The Journal
OF THE
Royal United Service Institution.

VOL. XIX. 1876. No. LXXXIV.

LECTURE.

Friday, February 12th, 1875.

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MILITARY BRIDGE-CONSTRUCTION.

By Lieut.-Col. ARTHUR LEAHY, R.E.[1]

WHEN a nation has decided to be prepared for war, the indispensable conditions are—

1. To enrol and train men to fight.
2. To provide *matériel* for their equipment.
3. And supplies for their maintenance.

These conditions being fulfilled, and war being decided on, one of the first military points which will necessarily come under the consideration of the General appointed to direct the war, is the *communications* of his Army; this consideration will, when the General is free to choose the theatre of his operations, largely influence his choice, and when not so free, the establishment and maintenance of his communications will be his first care. By communications are usually understood roads, railways, canals, and telegraph lines; but in the case of an insular power the first communications for the purpose of offence, are necessarily exceptional, and are established and maintained by the Navy.

It is one of the functions of an engineer to direct the works necessary for establishing and maintaining the first mentioned communications, and of these works none are of greater importance than bridges; hence it arises that "military bridge-construction" is one of the duties which a proportion of every military force should be specially trained to undertake.

In our own Service the subject has not, until a comparatively recent date, received the attention it deserves. Our recent wars have happily

[1] The publication of this lecture has been unavoidably delayed.

not been near home, our first lines of communications have been provided by our Navy, and in the only European expedition in which within the last 60 years our army came into collision with that of a Continental Power, we did not move a dozen miles from our ships. Yet who can read of the expedition to the Crimea without being impressed with the fact that many precious lives and much treasure were unnecessarily expended from the want of means, prepared beforehand, for establishing and maintaining our military communications. By a happy chance no serious inconvenience resulted from the want of a military bridge-equipment, for although no important rivers ran across the track of our Army, and the streams which had to be passed were, partly owing to the season of the year, in many places fordable, yet had the bridges which did exist, been demolished, and the fords been obstructed, the case would have been very different. I can testify to the anxiety that was felt when, entirely destitute of any bridge-equipment, we approached those streams; and I do not hesitate to say that had resistance been offered to the crossing of the Belbec and Tchernaya, and the aqueduct parallel to the latter stream, we should have been much embarrassed from want of preconcerted means for passing troops across a few yards of deep water.

There is not any speciality that has, throughout the period from which military history dates, preserved its importance more constantly in relation to the operations of war than "bridge-construction." It influenced such operations ages before many of the arms and appliances now in use were thought of, and the necessity for its study and practice is now as great, if not greater, than ever.

In railways a new element of immense military importance has arisen, and I need scarcely say that for railways, bridges are more indispensable than they were for any pre-existing communications.

Military bridges are of two classes—

1. Those formed on floating supports or piers.
2. Those of which the supports are fixed.

They may be wanted to complete the communications of an army where no bridges exist, where permanent bridges have been destroyed, or require to be supplemented either with the object of separating the combatant troops from the baggage of an army, or because the roads or tracks leading to the bridges, admit of the advance of troops on a larger front than the width of the permanent structure.

In such cases, one or more temporary auxiliary bridges may be wanted for each road, and these, by increasing the means for rapid movements,—now so essential in military operations,—may contribute largely to success.

It would be beyond the scope of this lecture to dwell at any length on the influence of bridges on strategic or tactical operations, and I can, therefore, only call attention to a few important examples of bridges which have been constructed for military objects.

The first military floating bridge of which we have any detailed account, is that constructed by Xerxes more than 2,355 years ago, and over which his host, estimated at above five millions of souls, were, during seven successive days and nights, marched into Greece;

but this, however, would appear to have been preceded by other important bridges constructed by the Persians across the Thracian Bosphorus, and the Danube.

The bridge across the Hellespont was about 1½ miles long; there were two roadways, one formed of 360 ships or boats, the other of 314. One of these roadways was set apart for the combatant troops and the other for the attendants and baggage animals. In each case the vessels were connected by enormous cables, stretching from shore to shore, which were tightened by windlasses on either side, and superlaid with planks, brushwood, and earth, formed the roadway. It may not be without interest to some of my military audience to remind them that the first attempt to construct this bridge failed, owing so far as I can discern, to the neglect of one of the simple principles of bridge-construction, and that this first failure cost the bridge-constructors their lives.

We also read in Xenophon that Cyrus found bridges across the Mæander and Tigris, the former being composed of 7, the latter of 37 boats.

Skins inflated, or filled with hay, were used for crossing rivers by the Greeks, notably by Alexander the Great for the passage of the Oxus. Casks were used by the Romans on several occasions for a like purpose. It was also customary for the Romans to carry with them small boats, together with planks, nails, and ropes, for crossing rivers without loss of time.

Of fixed bridges, the first notable example is that constructed across the Rhine by Cæsar. I produce a model showing how the trestles of this bridge, which was of great strength and solidity, appear to have been put together. It took ten days to construct.

There are numerous instances in which the Rhine has been bridged for warlike operations.

The passages of that river, for purposes of attack by Jourdan in 1795, and by Moreau in 1797 and 1800, are celebrated.

Moreau's passage in 1797, is stated to have been one of that great General's most remarkable enterprises, and was thus effected:—

His Army, some 60,000 strong, shared with that of Hoche, some 70,000 strong, the possession of the left bank of the Rhine from Kehl to Dusseldorf, and the two Generals were ordered to operate simultaneously against the Austrian forces on the right bank in order to create a diversion in favour of Napoleon, then engaged against the Austrians in Italy. Hoche crossed the Rhine without difficulty at Nieuweid, where he had a footing on the right bank, but Moreau had to cross in face of the enemy.

He therefore collected about 60 boats, 40 of which were brought down the Ill, on the dark and stormy night of April 19–20, 1797, with the intention of being used to pass troops across the river at dawn, and thereby surprise the Austrians. The boats were, however, delayed by grounding on a sand bank, and only 25 were forthcoming at 5 A.M., on 20th April, when a fresh delay arose. In the Ill, which was shallow, the boats were poled along. The oars, necessary in the Rhine, had been stowed in one of the boats which had grounded.

An hour was lost in procuring them, and meanwhile, the idea of a surprise had to be abandoned.

The French flotilla, on arriving at the Rhine, found itself in view of the Austrian batteries, which commenced to fire on it. The pontooneers, however, who managed their boats with skill and coolness, succeeded in landing the troops out of grape-range, and went back for other detachments. The French troops sustained themselves on the right bank until reinforced by troops, thrown across:—1stly. By a flying bridge, which was subsequently destroyed by artillery fire. 2ndly. By a floating bridge constructed between 6 P.M. and midnight on 20th April. This latter bridge was, with difficulty, formed under artillery fire from the Austrian batteries.

When this bridge was completed, the troops of Moreau's Army were in a position to take the offensive, which they did, and the operation ended in the retreat and route of the Austrian forces.

The military history of the 17th, 18th, and of the early part of the present century, abounds in examples of important uses made of military bridges. I will now only mention a few of those which appear worthy of special notice.

A bridge 380 yards long, constructed across the Danube at Deckendorf (1740), remarkable for being withdrawn by wheeling it entire along the bank ("swinging bridge" is the technical term used) after the rear-guard of the Army, when closely pressed by the enemy, had crossed it in retreat.

The bridge across the Limat, between Lake Zurich and the Aar, formed (1799), in two and a-half hours, under fire of a Russian force. The bridge was about 100 yards long, and the operation was covered by a detachment previously sent across the river in row-boats.

At the same time Soult forced a passage across the Linth, between Lakes Zurich and Wallenstadt, his troops being passed across on flying bridges, covered by a selected company of expert swimmers, who had been trained to swim, armed with pistols and sabres.

In the spring of the following year (1800), Moreau forced a passage in the face of Austrian troops, across the Rhine, near Lake Constance, a little below Stein. It was intended to have formed the bridge at night, but owing to delay in the arrival of troops, this was not possible, and the bridge was made in the early morning, under cover of artillery fire. By 9 a.m., all Moreau's corps, numbering three divisions and a reserve of cavalry, had passed over it, and were formed on the right bank. In this case the pontoons were carried by hand over ground not practicable for wagons, and the operation is remarkable as showing the importance of having a bridge-equipment capable of being used as boats, and at the same time not too heavy to be carried by hand.

The bridge constructed in 1814 across the Adour, from the left wing of the Duke of Wellington's army, and of which there is a model in this institution, ranks high in importance and interest. It was constructed of boats and cables, on the same principle as the bridge of Xerxes already described.

The passage of the Berisina, during the retreat of Napoleon from

Moscow in 1812, affords one of the most remarkable instances of the importance of maintaining a bridge-equipment as part of the materiel to be moved with the advance of an army, and is also an example of valuable services rendered by Pontooneer corps in constructing improvised bridges under circumstances of peculiar difficulty.

During the month of November, 1812, Napoleon, in his desire to reduce to a minimum the inconvenience of a long train of baggage, ordered a large number of wagons to be destroyed.

Among these was included his pontoon equipment, which, against the remonstrance of General Eblé, the Officer charged with the direction of the bridging operations of the Army, was burnt.

General Eblé, foreseeing the difficulties likely to arise from this proceeding, gave orders that every pontooneer should carry with him some kind of implement, or nails, useful for bridging operations, he also managed to retain two forges and six wagons, containing tools and ironwork, from the wreck for his train, and, with remarkable foresight, he added some charcoal for his forges.

Napoleon's march was directed to the Berisina, and he made his plans to cross that river by the bridge at Borisow, which was then held by his troops; but, on 23rd November, he received the news that his troops had been repulsed, and that the Russians were in possession of the bridge which they afterwards burnt.

The Russians, who were in great strength on the right bank of the river, expected that Napoleon, checked at that point, would endeavour to pass the river below Borisow, and directed their attention to the lower Berisina, while Napoleon, with great judgment, decided to attempt the passage some leagues higher up.

On the 24th November, Napoleon sent for General Eblé and explained his plans. The Berisina, at the point where the passage was decided on, was less than 100 yards wide. The greatest depth was from six to seven feet, the bottom was muddy, the current moderate, and loose ice drifting down.

Had one-tenth of the bridge equipment which had been burnt a few days before, been available, the passage of the river would have been a simple matter.

In the absence of this equipment, bridges had to be improvised, and had it not been for the foresight of General Eblé, this would have been impossible.

It was decided to construct two trestle bridges; one a light bridge for infantry, and a stronger bridge for artillery and for baggage.

General Eblé lost no time in setting his pontooneers to procure materials for the bridges from the neighbouring village of Studianka. Trees 16 to 17 feet long and 5 to 6 inches in diameter, and timber procured by the destruction of the village, were the available materials.

By about 5 P.M. on 25th November, 46 trestles were prepared, 23 for either bridge. In order to place the trestles, the pontooneers had to work by night in the water, the ice forming around their limbs, adhering to their flesh and causing intense pain. By 1 P.M. on the 26th November, the light bridge was completed, just in time to enable about 7,000 men to be passed over the river, to hold in check the

advance of the Russian troops, who, on the discovery of the attempt, had begun to move towards the point at which the bridges were being erected. The flooring of this bridge was formed of light planks taken from the houses, and it was barely passable for horses. A few light guns and some ammunition-wagons were, however, passed over by hand.

By 4 P.M., the bridge destined for carriages was completed, and the artillery and other wagons began to cross. Many of the trestles and the roadway of this bridge were composed of round timber rudely fitted with axes, and the movement of the carriages on so rough a surface, and the pace of the horses, which, notwithstanding orders that had been given to the contrary, were permitted to trot, caused the most violent shocks to the bridge. The trestles sunk unequally in the muddy bottom and eventually some of them gave way, and the traffic was several times interrupted.

The pontooneers worked by reliefs throughout day and night, and with wonderful devotion and endurance of cold and fatigue, managed to repair the bridge, so that during the 27th and 28th November, the troops and a number of followers, and a portion of the baggage of the Grand Army, were, notwithstanding the attacks of the Russians on both banks of the river, passed across in safety.

Segur, writing of this exploit, observes that the exertions of the pontooneers "sauva l'Armée," and Thiers says of General Eblé, who, with a large number of his devoted pontooneers, shortly afterwards succumbed under the hardships they had endured, that he crowned his career by an immortal service. ("Allait couronner sa carrière par un "service immortel.")

Russian War, 1854–6.

During the war with Russia, 1854–6, floating bridges were made use of to cross the Danube. A raft-bridge with carriage and footway was formed by the Russians near Galatz.

A bridge of boats 970 yards long, was formed, by detachments of British and French engineers and British sailors, between Rustchuck and the Island of Mokan, and a trestle bridge connected the latter island with the main land. Over 100,000 men crossed and re-crossed this bridge.

The raft-bridge thrown across Sebastopol Harbour with remarkable rapidity in August, 1855, and removed in the following month after the garrison had retired by it, was 1,000 yards long and 17½ feet wide. It enabled the Russian reserves to be kept secure from the effects of the fire of the siege guns by day, while at the same time they were at hand in case of assault, or for purposes of night attack.

During the embarcation of the British and Sardinian forces at Balaclava Harbour, numerous cask-bridges were formed between the ships and the shore, by which troops, horses, and stores were brought up to the ships' sides, and the embarcation was thereby very much facilitated and expedited.

Indian Mutiny, 1857–9.

The river Ganges was on three separate occasions crossed by the Oude Field Force during the rainy season of 1857.

July, 1857. On the first occasion the troops were ferried across in boats, an operation which took eight days.

August, 1857. On the second occasion, the distance was shortened by the construction of a causeway and pier a mile in length, and three bridges, of four, six, and twelve boats across some narrow channels, and the actual passage of the river was completed in one day.

September, 1857. On the third occasion, the communication was completed by a bridge, 1,090 feet in length, composed of 74 boats with improvised superstructure, anchors, and cables. It was constructed by undisciplined workmen and labourers, under the direction of engineer officers, in 42 working hours. In this case the force marched across in a few hours.

Italian War, 1859.

A bridge of 97 river boats was constructed under the orders of Prince Napoleon, on the Po, at Casalmaggiore.

American Civil War, 1861–63.

From the Civil War in America, 1861—63, may be dated a new era in military bridge-construction. In that war for the first time, arose the necessity for the hasty restoration of railway bridges in connection with military operations; and of the works carried out, the most notable is the trestle bridge across the Potomac Creek on the Richmond, Fredericksburg, and Potomac Railway. This bridge, the trestles of which resembled the model before you, required in some places three tiers of trestles, each about 20 feet in height.

This and most other forms of military railway and other kinds of temporary bridges, are fully described in the valuable work on Military Bridges, published in 1864, by Colonel Haupt, formerly chief of the Construction-Department of Military Railways in the United States' Army.

In this text book, much of the technical information given by Sir Howard Douglas is reproduced corrected to date, and with the addition of the important experience of the author.

The general success which attended the bridging-operations of the Americans during the Civil War, is admirably illustrated by an exceptional case of failure producing most serious results. This occurred when Burnside crossed the Rappahannock, in face of Lee's position overlooking Fredericksburg, with a view to making a direct attack on the Confederate lines, and, as is well known, one of the most crushing defeats of the war, entailing a loss of over 10,000 men, there occurred.

General Franklin, one of the corps' commanders, on whom the most important share of the action fell, officially stated before a Committee of the Senate, held at Washington:—That this disaster resulted from the delay in the arrival of the pontoon-bridges, and that whoever was

responsible for this delay, was responsible for all the disasters which followed.

Danish War, 1864.

During the Danish War, 1864, a bridge, 280 yards long, was constructed over the Schlei in $2\frac{1}{4}$ hours.

Troops were also thrown across to the Island of Alsen at night, *under fire*, in rafts each of two pontoons. Light artillery was also taken on the rafts.

The crossing took place at four stations, where the river was respectively 700, 900, 1,000, and 2,500 paces wide.

Austrian War, 1866.

Previous to this war, Prussian Officers had reconnoitred and measured the permanent bridges likely to be destroyed, and materials for their repair were prepared and fitted together beforehand.

Some of the bridges were subsequently repaired with these materials.

After the battle of Sadowa, the Austrian Army under Benedek, was saved from ruin by 6 strong pontoon bridges thrown across the Elbe, in the rear of the position.

German War, 1870–1.

The important services rendered by the bridge-trains attached to the German Army corps during the war of 1870–1 can best be appreciated by a glance at the Table in the Appendix which gives particulars of some of the bridges actually constructed.

The first important occasion on which bridges were required, was at the battle of Wörth. Early in that action the necessity for providing means of crossing the Sauer arose, but the bridge train of the XI Army Corps had, against the remonstrances of the Commanding Officer of Engineers, been left in the rear.

Delay and loss consequently occurred in crossing the river; foot-bridges were, however, improvised out of hop poles, and later in the day regular bridges were constructed, the pontooneers were, during the construction of these bridges, harassed by sharpshooters in the neighbouring houses.

Ashantee War, 1874.

It is exactly one year since, in our latest war, Sir Garnet Wolseley recrossed the bridge over the Prah, after the capture of Coomassie.

The events of that war are fresh in your memories, and were a few months ago graphically described at this Institution by principal actors therein.

The total number of bridges constructed during the war, was over 250.

I invite attention to the examples of bridge-construction used, of which models and diagrams are before you. These bridges were, as it is right they should have been, simple in character; and they were not required to carry any very heavy loads. Merit, greater than often attaches to more extensive works, is, however, due to the bridge-con-

structors, under whose direction the bridges were erected, inasmuch as they were put up under difficulties of no ordinary kind, with very small means both in men and materials, and with few of the appliances usually considered necessary for such works.

Of the bridges constructed during this war, by far the most important was that across the Prah, and the following account of the arrangements made for its construction has been given by Lieut.-Colonel Home, C.B., the Commanding Royal Engineer of the expedition:—

Bridge across the Prah.[1]

On arriving at the Prah, it was found that the stream was 189 feet in width, the depth varying from 3 to 10 feet.

Four small Blanshard's pontoons were the only means available for crossing, and were far too few to rely on, for the vast number of carriers that had to pass to the front.

Twelve trussed-girders, each 30 feet long, had been prepared at Chatham. These were very light and strong, and, with 5 supports, would give a bridge across the river 2 feet 6 inches wide.[2] But considering the very important link in the communications this bridge would be, it was determined to make it not less than 5 feet wide.

Thus, the trussed-girders would give one-half of the roadway required, and the remainder consequently had to be made up of material to be procured on the spot.

At Cape Coast Castle, some light trestles had been prepared, but examination showed that they would not be nearly strong enough.

A section was made of the river which showed that the bottom was fairly regular, and of hard sand. There were no means of driving piles, and such light trestles as the tackle on the spot would get out, would undoubtedly be carried away in a short time, as the current was running nearly four miles an hour, and freshets were to be expected.

Under these circumstances the use of crib-work piers was determined on.

On the 26th December, 1873, a rope was got across the river, so as to haul the pontoon-rafts backwards and forwards. This rope served also to keep off any drift-timber that might float down the stream, from damaging the bridge.

A place for the bridge was definitely selected, and a party put on to cut the bank down in a ramp, a considerable work, as it was 30 feet above the water.

The place selected for the bridge was below a projecting point on the bank, which produced a small eddy; this eddy was selected as a convenient place for launching the cribs.

A stake was fixed in each bank so as to mark the centre line of the bridge, and a take-off was prepared by fixing a trestle in the water as deep as the men could work, or about 5 feet; this take-off, spanned

[1] Models of this and of several other forms of bridge-construction are in the Museum (presented by Colonel Leahy).

[2] The trussed-girders were the development of a girder which had been proposed in 1856 by Major-General Bainbrigge.

about 9 feet, and was made of rough timber, and as strong as it conveniently could be. A crib was then constructed on ways; it was 8 feet by 6 feet at the bottom, and battered up to 4 feet by 3 feet at the level of the water.

Two anchors were laid out, and barrels were attached to the crib to give it some additional buoyancy, the timber being very heavy, four sand-bags were filled, and lashed one in each corner of the bottom, which was composed of a cross-barred frame. These sand-bags and the barrels caused the crib to float vertically.

The bight of the cable between the anchors was adjusted so as to be nearly 30 feet clear of the shore-end (see Plate XXXI); a buoy with a block was attached; a rope rove through the block as a haul out; a rope was carried to the other side of the river, and the crib was launched down the bank, a preventer rope being passed round a tree at the top of the bank to keep it from going too fast. It was found to float generally 2 feet out of water.

The haul-out was manned, the crib hauled up to the block on the bight of the cable, and then allowed to drop slowly down to its position; a rope 28 feet long was attached to the shore-end of the bridge, so as to allow a bearing of 1 foot at each end, and so soon as the crib got into its proper position, the pontoon-raft, loaded with sand-bags, came close up, the slip-knot attached to the barrels was let go, the barrels floated up, and sand-bags were thrown into the crib, mixed with rice-boxes and bread-bags (there were only 100 sand-bags available.

The day after the first crib was launched, it was found to have sunk 17 inches into the mud, and to be only 4 inches out of level; this was easily made up by putting a couple of thick sticks on the low side.

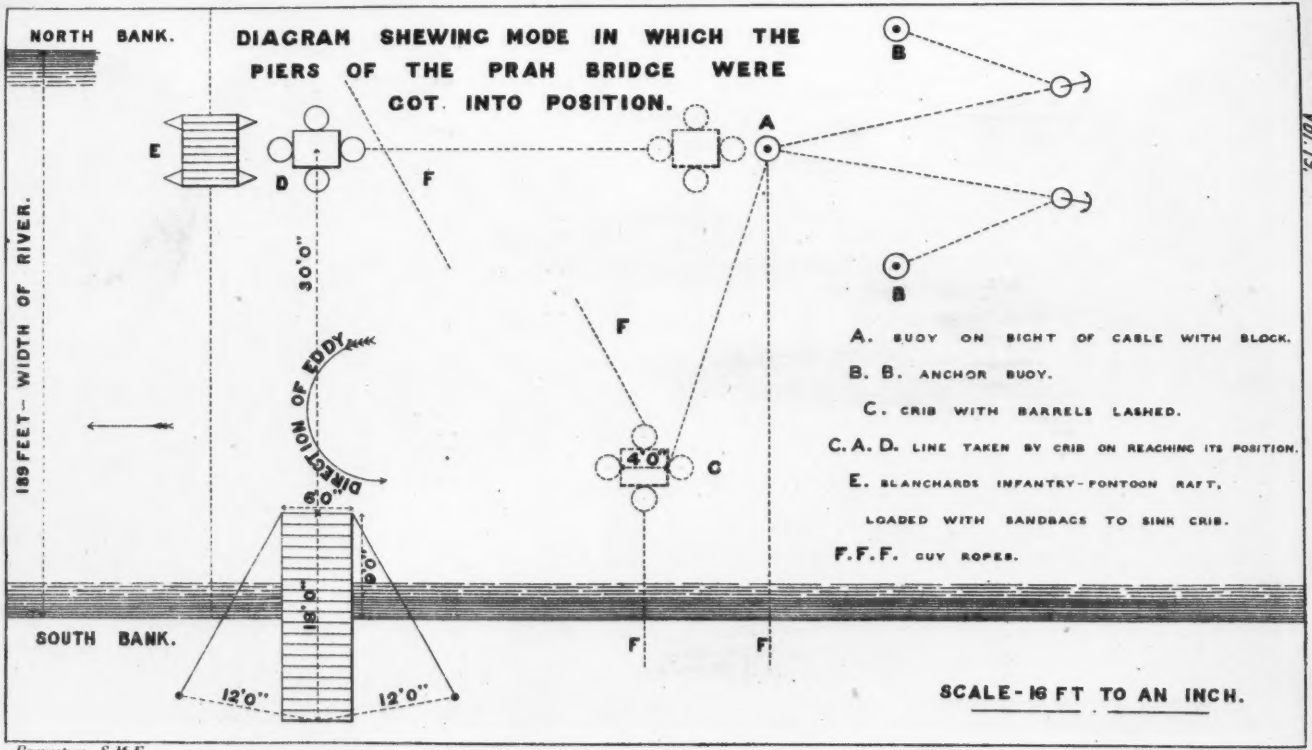
The crib was raised to its full height, and transoms of roughly-adzed timber laid on. The girders were next got into position, and the first span of the bridge was thus completed.

The Major-General having directed that the bridge should not be gone on with until his arrival, nothing further was done with it until his arrival on the 3rd of January, when it was begun at both ends, and finished on the 5th. The spans, where native timber was used, were reduced to 20 feet, as nothing was known of the bearing power of the timber.

The third crib from the south bank, and consequently the middle of the river, was the only one that gave any trouble.

It grounded on a large stone, about 3 feet out of the proper line, and could not be got to float over this stone, although a considerable lifting-power of barrels was applied to it. It was therefore loaded, and the roadway formed over it, the top being levelled up with thick timber on the low side; next day, this crib was found to have slipped 15 inches out of its place; to secure it temporarily it was strutted with piles. The shore side on the north bank was carried on three trestles made of rough timber lashed and braced together. (See Plate XXXII.)

The bridge should have been finished on the 5th, at 10 A.M.; it was not, however, completed until 3 P.M. the same day, when the rear-



PL. XXXI.

Papyrotype. S.M.E.

PL. XXXII.

BRIDGE AGROSS THE PRAH, 1874.

guard and baggage of Russell's regiment moving to the front, passed over it.

The crib that was out of place, showing symptoms of moving, it was relieved by driving strong piles on each side, and the roadway was carried on a cross transom lashed to these piles.

The crib was thus useless, and might have been removed, but it did no harm, and was left in its place. The cribs were all finally lashed with a 3-inch hawser, the roadway secured with telegraph-wire and 10-inch spikes; each crib was further strutted on the down-stream side and an apron of sand-bags and rice-boxes thrown in to prevent any movement; a hand-rail was subsequently added.

On February 11th, 1874, a report was sent to the front to say that the Prah was rising rapidly, and that the bridge was in great danger, but happily on exactly this day twelve months, all anxiety on this score was removed; although the flood rose nearly to the roadway, the bridge was six weeks after, apparently in the same state as when completed, and did not appear to have suffered at all.

The entire number of working hours taken in making the bridge was 61.

The Royal Navy helped greatly in the construction of the bridge, there being only five sappers fit for duty at the Prah.

Military Bridge-Construction.

The conditions to be borne in mind in constructing military bridges, together with the details of the loads due to the passage of troops of various arms, guns, &c., and the formula for calculating the strength and buoyancy of the materials are given fully in our text book on military engineering, from which I have abstracted most of the technical details given in this lecture.

A very convenient epitome of the information required in the field is given in the "Soldier's Pocket Book."

The following points should be borne in mind when constructing military bridges:—

1st. In whatever formation troops are to pass, the bridge should be capable of carrying them when crowded.

2nd. A roadway 8 feet wide in the clear, will admit of the passage of infantry four deep, and of all descriptions of military wagons in one direction, but the width between the hand-rails should not in any case be less than 9 feet; a wider roadway is, if the supports of the bridge admit of it with safety, very desirable, so as to allow Staff Officers or orderlies to pass in a direction contrary to the stream of traffic. In very light bridges, more especially in suspension bridges, the width of the roadway may have to be reduced to the minimum necessary for the wheels of the carriages that have to pass over it, guides being fixed for the wheels. It must be borne in mind that parts of wagons extend beyond the wheel track. The width of a double roadway should not be less than 16 feet. The headway should not be less than 9 feet, and the floor of floating bridge should ordinarily be not less than $2\frac{1}{2}$ feet above the water-line.

Ramps at the end of a bridge if intended for artillery should not

have a slope steeper than one-seventh, but slopes greater than one-tenth are inconvenient, more especially for animals.

Loads on Military Bridges.

The following are the principal loads that can be brought on a bridge by the passage of troops of various kinds, guns, &c. :—

Infantry in marching order, average weight 200 lbs. per man, cause, when crowded, a load of $1\frac{1}{4}$ cwt. per lineal foot of roadway.

Infantry in marching order, in file, crowded, cause a load of about $2\frac{1}{2}$ cwt. per lineal foot of roadway.

Infantry in marching order in fours crowded, cause a load of 5 cwt. per lineal foot of roadway.

Infantry in marching order, when crowded in a disorganised mass, may cause a load of 100 lbs. per *square* foot of standing room, and unarmed men, average weight 160 lbs. per man, may, when crowded in a disorganised mass, cause a load of 133 lbs. per *square* foot of standing room; this, in a bridge 8 feet wide, would be about 9 cwt. per foot lineal of roadway.

Cavalry in marching order, in file, each man and horse together weighing about 1,400 lbs., and occupying 12 feet lineal of bridge, cause a load of about 1 cwt. per lineal foot of roadway.

Cavalry in marching order, in file, crowded, cause a load of less than $1\frac{3}{4}$ cwt. per lineal foot of roadway.

Cavalry in marching order, in half sections, crowded, cause a load of nearly $3\frac{1}{2}$ cwt. per lineal foot of roadway.

The following table gives the weight of field guns, &c., fully loaded for travelling :—

Description of gun, &c.	Weight upon fore and hind wheels respectively.	
	Fore, or limber.	Hind, or gun.
	cwt. qrs.	cwt. qrs.
16-pr. M.L.R. gun (iron)	16 2	25 2
9-pr. „ „ „ of 8 cwt.	12 0	19 2
16-pr. ammunition wagon	17 0	23 3
Pontoon wagon	15 0	24 0
Wire wagon	15 3	22 3
General Service wagon with springs — heavy	28 1	34 4
General Service wagon with springs — light	18 3	26 3
Small arm ammunition cart	—	19 0

For calculations of strength and buoyancy, the following classification of bridges may be found convenient.

1. Foot bridges for infantry in single file; breadth of roadway up to 3 feet; maximum load per lineal foot of roadway about $1\frac{1}{4}$ cwt.

2. Infantry bridges for infantry marching two abreast; these bridges would usually be available for cavalry in single file, leading their horses and light guns passed over by hand. Breadth of roadway, 6 feet; load per lineal foot 2½ cwt.

3. Advanced bridge equipments available for a field force of infantry in fours, cavalry in half sections and field artillery; breadth of roadway, not less than 8 feet. Load about 5 cwt. per foot run.

4. Heavy bridges adapted to the passage of siege artillery. These usually require to have special arrangements made for strengthening the roadway and supports.

It should be noted that the greatest weight which the pier of a bridge is likely to sustain during the march of an Army, is caused by crowded infantry, and that the weight of crowded cavalry may be greater than that of artillery. It is necessary to bear this in mind—because during the passage of the Elbe at Priestnitz, in 1813, the Officer in command of the cavalry, thinking that because the artillery had passed there was no reason to question the security of the bridge for cavalry, let his files close up, and afterwards trot, the result was, that the bridge broke down.

Sites for Bridges.

In choosing a site for a bridge across a river, the chief points to be recollected are:—

1st. The site should be as near as possible to the main communications.

2nd. The position most easily defended is a re-entering bend, where the bridge may be secure from fire, and the ground in front exposed to a cross fire from the near bank.

3rd. The bridge should, if possible, start under cover of a commanding bank, woods, or undulations, while the opposite bank should be open.

4th. Banks or marshes which make the approaches to the bridge difficult, or portions of the stream with very strong currents or shoal-water, should be avoided.

5th. In tidal rivers, banks steeper than $\frac{1}{7}$th, or beds likely to injure the piers when grounded, should be avoided.

6th. In attempting the passage of a river in face of an enemy, every practicable ruse should be devised to conceal the point at which the passage is to be made.

7th. The first operation should be undertaken with detached means, such as row-boats, rafts, and flying bridges prepared beforehand, and concealed until the passage is to be attempted.

A *flying bridge* is one in which the action of the current is made to move a boat or a raft across the stream, by acting obliquely against its side.

I have already stated that military bridges are of two classes, viz.:—

I. Floating, } bridges.
II. Fixed }

These may again be considered under two heads:—

1st. Those formed of bridge-equipments prepared to accompany an army.

2nd. Those improvised out of such material as can be locally procured.

In designing a permanent bridge, solidity, durability, and economy are the chief points the engineer has to consider; but a condition under which military bridges have in nearly all cases to be formed, is *rapidity of construction*, and consequently the necessity for this has to be kept in view in all typical forms of bridges proposed for the equipment of an army, or for the instruction and practice of troops.

Another condition which, though not common to all cases, is in many even of more importance than the first, is *portability*.

Subject to these conditions, there is little difference between the kind of technical knowledge required in a military as compared with a civilian bridge-constructor; but it will be manifest that experience in the direction of skilled labour, and practice in turning local resources to the best account, are desirable, if not necessary, qualifications in a military bridge-constructor.

Improvised Field Bridges.

The types of improvised bridges constructed in carrying out the courses of bridging laid down for our troops are of the two kinds already mentioned—

I. Floating bridges.

II. Bridges with fixed supports.

The fixed bridges are of four kinds, namely:—

1st. Trestle and pile bridges, applicable to rivers or gaps where the bottom is available for supports.

2nd. Frame bridges used for clear spans up to 60 or 70 feet.

3rd. Tension bridges used for clear spans up to 100 feet.

4th. Suspension bridges, which may be used for still larger spans.

For improvised fixed bridges, timber (often green and in the rough) is the material most frequently available.

The ordinary fastenings are rope lashings, wooden trenails, and iron bolts and nuts, nails, spikes, and dogs.

For instructional purposes, round spars and rope lashings, materials which admit of being used repeatedly, are generally employed, hence the term "spar-bridging;" but it should be clearly understood that the principles which regulate the construction of spar-bridges equally apply to structures in which timber of any other form, and other kinds of fastenings than rope are used. Iron fastenings are, of course, better suited than rope for semi-permanent bridges, and for those made of material not required for re-use.

Before troops are employed at bridging, they should be thoroughly instructed in the various knots and splices used in lashing spars together. The knots and lashings, a knowledge of which is essential for

spar-bridging, are few in number, they are easily learnt, and if not practised, are easily forgotten.[1]

Trestle Bridges.

Trestles are most useful in establishing communications across shallow rivers, having sound and hard beds, and which are not subject to sudden floods; for crossing ravines (up to 30 or 40 feet deep), where the bottom is available for support; and for crossing roads in use.

They can be readily constructed of any kind of timber, and are easily placed in shallow water, but are not so suitable for deep muddy rivers. Light rails and sleepers have been used for making trestles.

Single frame trestles may be used in streams 6 feet deep, and running with a velocity of 5 feet per second (equal to $3\frac{1}{2}$ miles an hour), or in deeper streams if the velocity of the current be less. They are suitable for any kind of tolerably firm bottom.

Tripod trestles may be used in water up to 6 feet deep, with a velocity of 5 feet per second, and in streams with muddy beds. Their great advantage is, that if the water rise, or one tripod sink into the mud more than the other, the level of the roadway can be readily adjusted.

When timber is plentiful, it has sometimes been found best to build solid piers of crib work, weighted inside with stones, &c., instead of using trestles. The piers of the bridge across the Prah were of this nature.

Pile Bridges.

When the legs of the trestles or supports are driven into the ground, they are termed pile bridges.

The bridge across the Ordah was of this type.

It was made under the following conditions:—

The river Ordah, about 10 miles from Coomassie, was reached by the European force on the afternoon of the 3rd February.

The river was 80 feet wide and 3 to 4 feet deep, and the construction of the bridge was at once commenced, and with a short rest, continued throughout the night and was completed at 5 A.M. No material or fastenings of any kind except what grew on the banks were available; the only tools were axes.

On the return march on February 6th, the heavy rains had swollen the river, which rose 18 inches above the roadway. The bridge was damaged, but its reconstruction would have taken some hours, which could not be spared for the purpose. The force, except the rear-guard, including all baggage and stores, were, however, able to get over the bridge.

As night was coming on and the river was rising rapidly, the rear-guard forded the stream, the water being up to the men's shoulders, natives who could swim, taking over the arms and clothes.

[1] For technical details of Military Bridge Construction, see vol. i (Part III) "Instruction in Military Engineering." Edition, 1875.

Frame Bridges.

Frame bridges are used to provide intermediate points of support where piers resting on the ground or floating piers are not available. The length of the intervals between the supports depends on the strength of the available road-bearers, while the width of the opening and the depth of the footings below the surface, decide the form of the bridge.

The forms commonly used are:—*Single* and *double lock* bridges, which provide one and two points of support respectively, and *sling* bridges, which provide a larger number.

Types of these bridges are given in Plates XXXIII. to XXXVII.

Single-Lock Bridges.

The single-lock bridge (formerly called single lever) is not suitable for greater spans than about 30 feet; it is composed of two frames locking into each other, as shown in Plate XXXIII.; these frames should not slope more than two-sevenths. The bridge can be erected by a party of two Non-commissioned Officers and 20 men, half on each side of the stream or chasm, in two hours, provided proper stores are available and in position on either side of the stream.

Double-Lock Bridge.

The double-lock bridge (formerly called double lever) is suitable for spans of 40 feet, and consists of two frames locking into a connecting frame of two or more distance-pieces with cross transoms as shown in Plate XXXIV.; the opening is thus divided into three spaces, and the span of the road-bearers is about 14 feet. The bridge can be constructed by a party of three Non-commissioned Officers and from 24 to 48 men, and be completed in three to four hours.

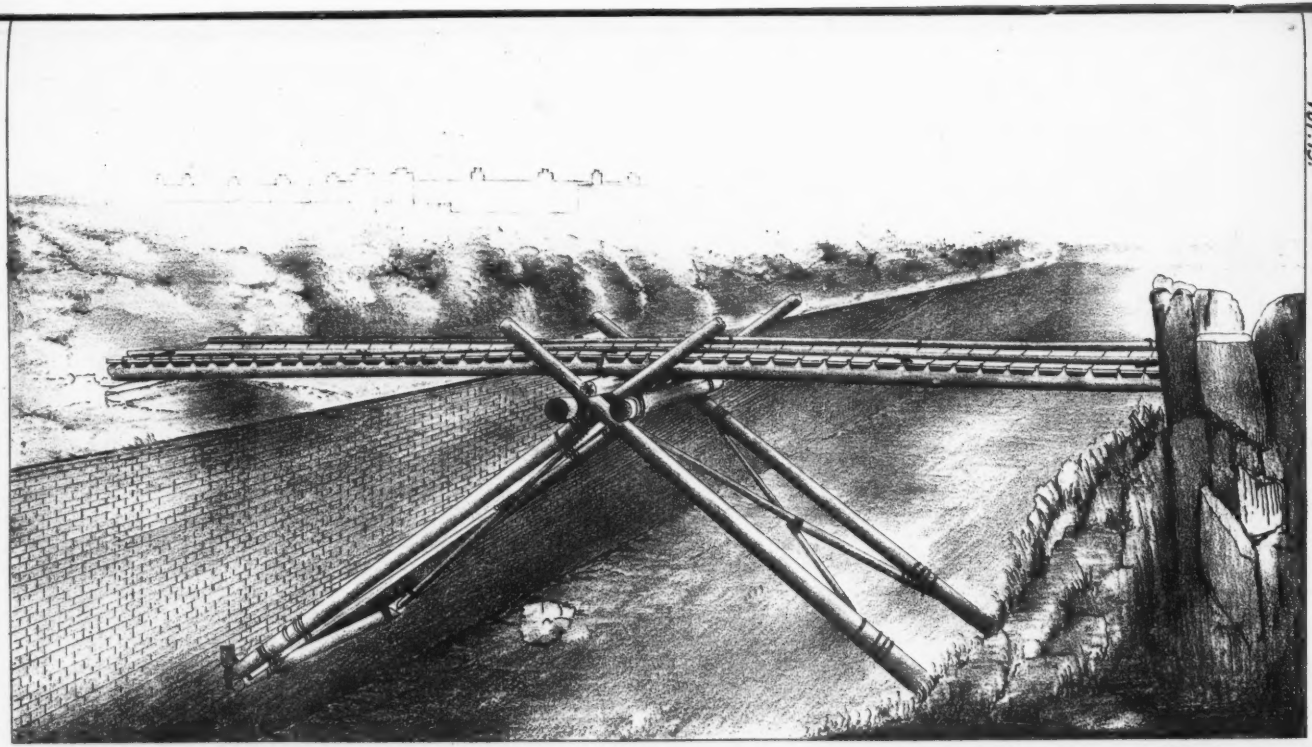
Single Sling Bridge.

The single sling bridge (formerly called the single truss) can be used for spans up to 50 feet; it consists of two frames locking into each other in the same manner as in the single-lock bridge, and provides three points of support, viz., one on each frame (a) and (b), and a third (c) suspended by slings from the heads of the frames (Plate XXXV). The bridge requires a party of three Non-commissioned Officers and from 30 to 48 men. The operation of getting the frames into position will require about four hours, and the roadway can be laid and bridge completed in about six hours.

For either of the foregoing bridges extra time should be allowed if the footings have to be cut in masonry or brickwork, as would be necessary in restoring a broken arch, or if trestles had to be formed as at (d) Plate XXXV.

Stiffened Single Sling Bridge.

The single sling bridge may be adapted to spans up to 60 feet by the arrangement shown in Plate XXXVI.



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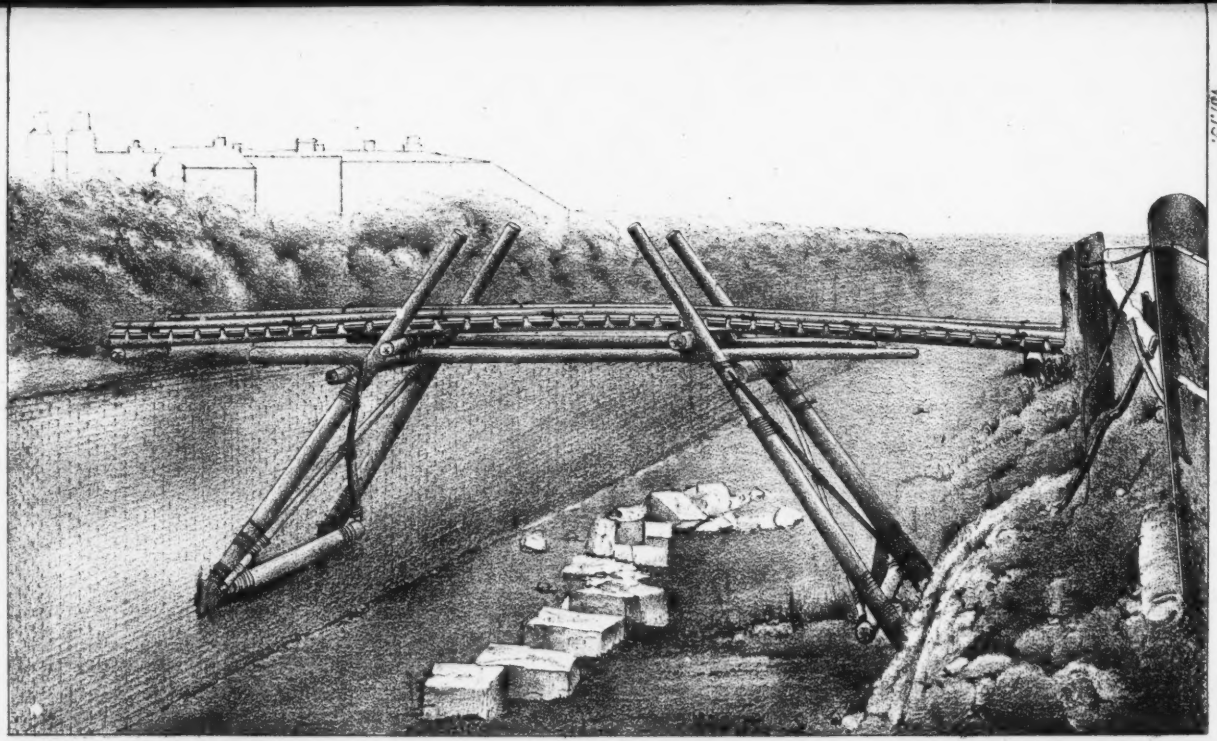
SINGLE LOCK BRIDGE.



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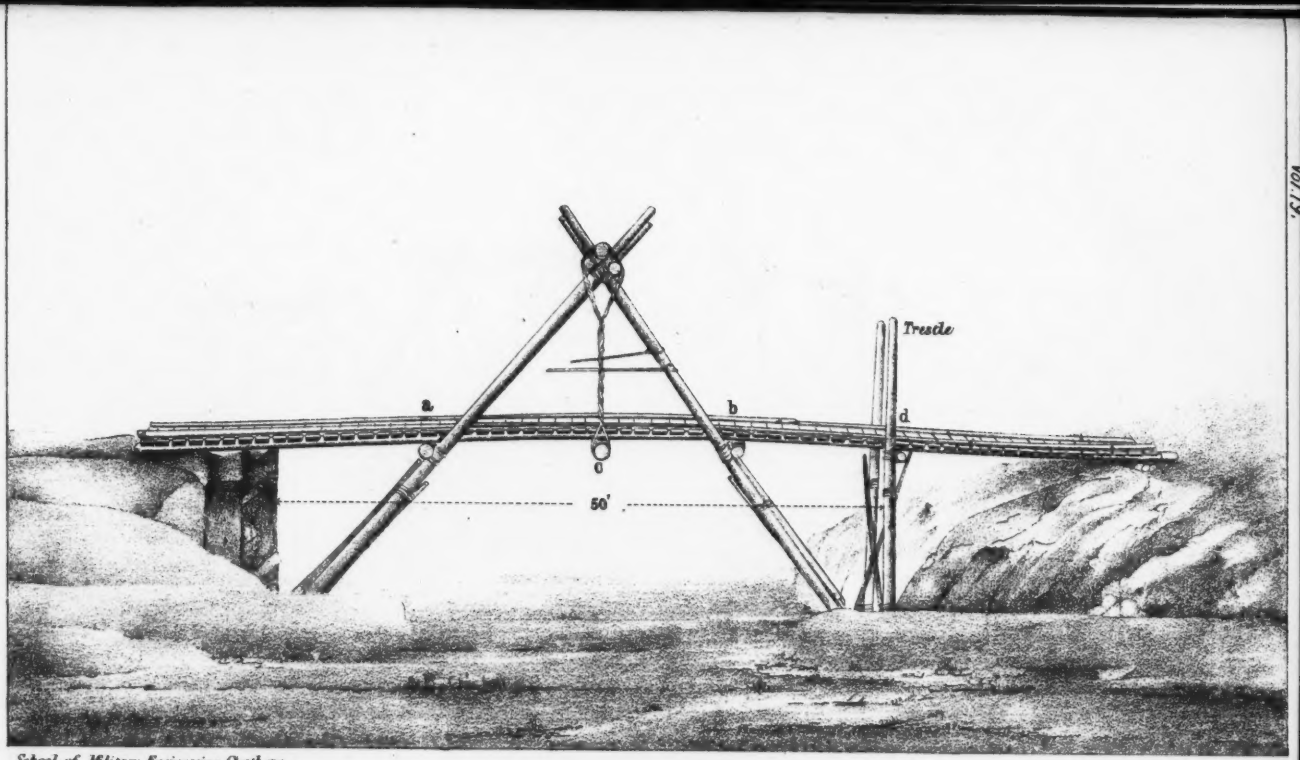
DOUBLE LOCK BRIDGE.



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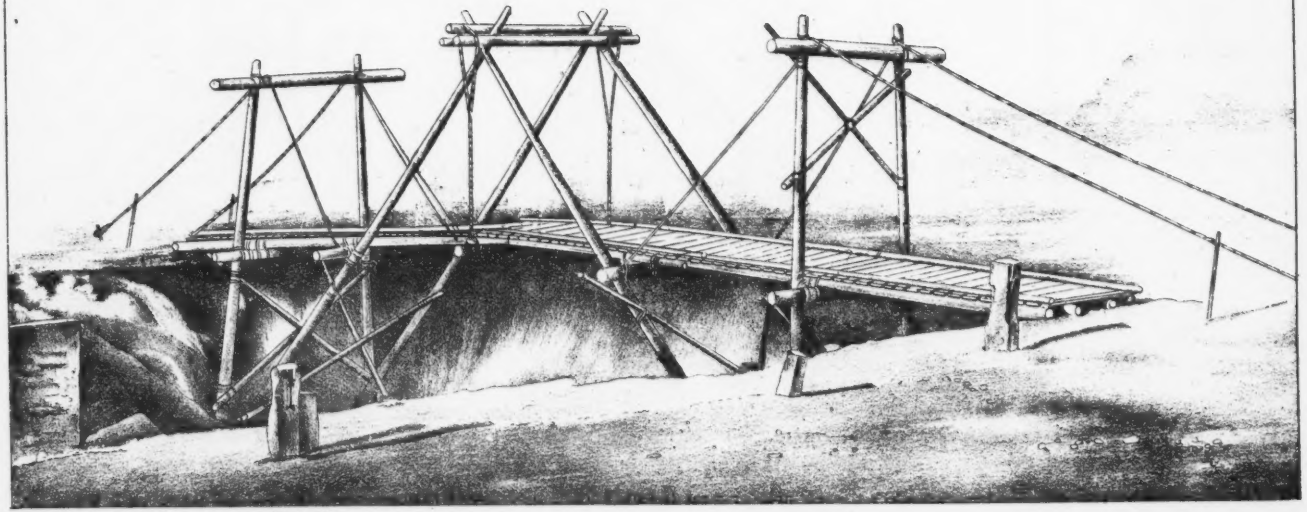
SINGLE SLING BRIDGE.



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STIFFENED SINGLE SLING BRIDGE

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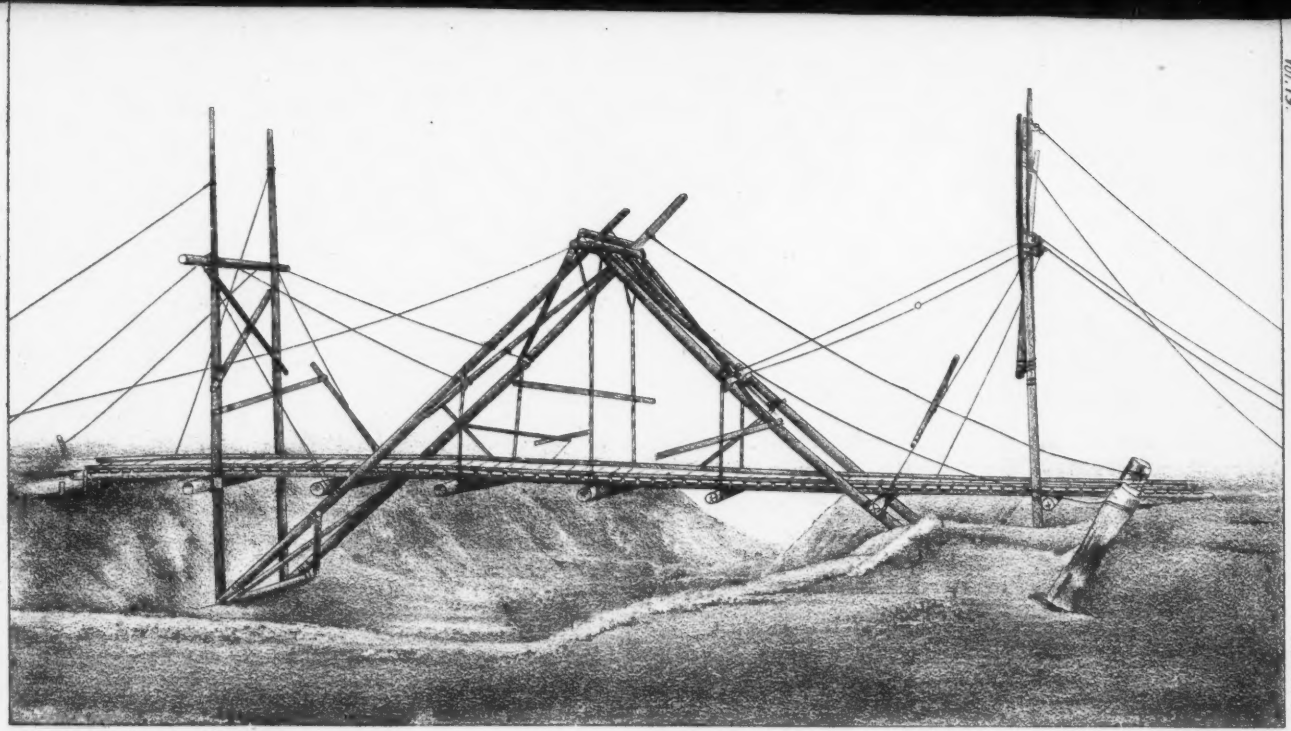

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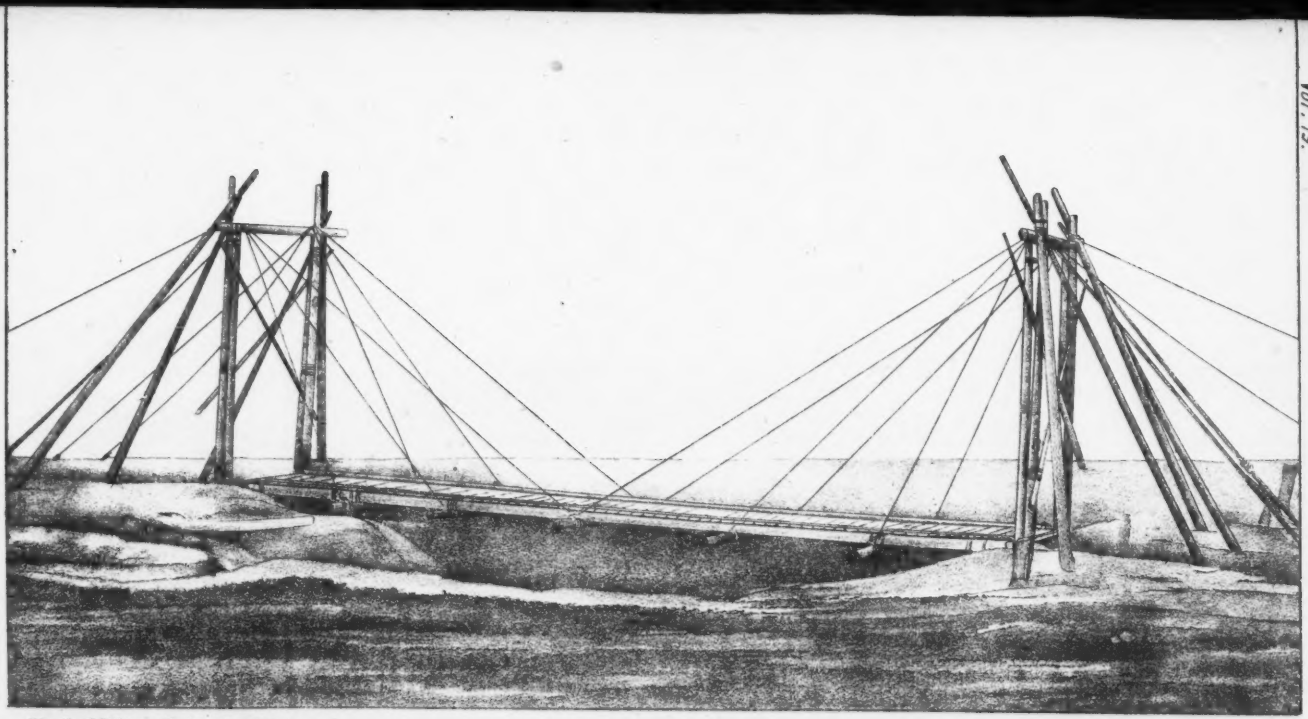
TREBLE SLING BRIDGE.



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TENSION BRIDGE.

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STRUTTED TENSION BRIDGE.

A bridge of this form (span between points of support 60 feet) was constructed so as to carry a 40-pounder B.L.R. gun (63 cwt. on hind wheels), and over 40 men $5\frac{3}{4}$ hours after it was commenced, the standards being yard-arms, two of them only 5 inches at the butts, the ties of hemp—(3 in.)—rope.[1]

Treble Sling Bridge.

The treble sling bridge stiffened by ties as shown in Plate XXXVII., is one of the strongest that can be made with spars and lashings, and may be used for spans up to 70 feet. This bridge only differs from the last in having each standard tied at two points instead of one, which allows the span to be divided into six parts.

A party of three Non-commissioned Officers and 36 to 48 men should make this bridge in six to ten hours if the materials were all at hand.

Tension Bridges.

When the span exceeds 60 or 70 feet, or when the standards required for frame bridges cannot be procured, tension bridges (examples of which are given in Plates XXXVIII. and XXXIX.), may be found suitable.

The advantages of these bridges are:—

1st. They are suitable for larger spans.

2nd. The ties are more easily transported than timber.

3rd. The roadway is as rigid as that of a spar bridge.

They take, however, longer to make than trestle bridges, and except with very strong materials, are only suitable for narrow roadways arranged to suit the track of the carriages which have to pass.

The strutted tension bridge (Plate XXXIX.) was constructed across a clear span of 100 feet, but is equally suitable for smaller spans.

Suspension Bridges.

In suspension bridging there are three convenient ways of using the suspension cables as supports for the roadway.

The first and most usual method is to hang the roadway below the cable.

The second is to lay the roadway partly on the cables and partly on baulks.

The third is to support a horizontal roadway on trestles carried by the cable.

The first provides a road fit for all kinds of traffic, but requires more materials than the others.

The second plan is the simplest, and requires least materials; it answers for troops and light guns.

The third provides a very stiff bridge, and saves having high piers, but is more influenced by wind, and is unfit for crossing water with banks lower than the heights of the trestles.

[1] This bridge was constructed by a class of Officers of the Guards, cavalry, and line, and some Royal Engineer recruits, under the direction of Captain T. Fraser, R.E. (Assistant Instructor in Field Fortification), by whom many of the details of the bridges described, have been worked out.

The site for a suspension bridge should be chosen with banks of the same height, and of sound rock or clay.

The best materials for cables are iron chains, steel or iron-wire ropes; hemp ropes, iron gabion bands, sail cloth, thongs of hide, and ropes of creepers or grass, or even small baulks pinned, or boards nailed together, are sometimes employed.

The roadway of a suspension bridge ought not as a rule to be wider than is necessary to allow of the passage of the vehicles it is to carry.

In India, suspension bridges for foot passengers are made of one or two cables, with hand-rails of rope or bamboo.

Floating Bridges.

Floating bridges afford a continuous roadway, supported on *piers* of boats, casks, or rafts. The piers are connected by beams, usually called *baulks*, on which a roadway of planks, usually called *chesses*, are laid.

Pontoon is the name given to a portable floating pier specially prepared for military bridges.

In floating bridges, each pier must have enough available buoyancy to support the heaviest load that can come over it. The piers should be at as wide intervals as their buoyancy and the strength of the baulks will permit.

The supports of a floating bridge should be at least twice as long as the width of the roadway, unless the buoyancy is much in excess of that required.

If it be not possible to make the bridge strong or wide enough to carry the different arms when crowded, notices should be put up at the bridge, stating what loads may safely cross.

Straw laid on the planks of a bridge deadens the noise for horses and prevents slipping.

In cases where there is a large tidal variation, the arrangement of bridge-ends, to be at all times available, is a work that requires much time, materials, and labour, and may be impracticable for hasty operations.

Cuts are sometimes wanted in floating bridges to allow traffic to pass, or to permit large floating objects, such as trees or ice, to be towed or guided through the bridge.

Boats or coasting vessels, &c., being frequently required in military operations for making bridges, it is necessary to be able to determine their flotation.

On rivers, boats are often of a nearly uniform section; this section multiplied by their length will give the cubic contents, and the cubic contents in feet, multiplied by $62\frac{1}{2}$, will give the weight of water displaced in lbs., and the consequent buoyancy.

With small boats, the easiest way is to load them with unarmed men to such a depth as is considered safe for bridging, then multiply the number of men by 160, and the result is the available buoyancy in lbs.

A rough rule for the proper interval between boats in bridge is to divide the number of men they safely hold by 4, and the result is the number of feet the boats may be apart from centre to centre. Thus, boats holding 60 men might be at 15 feet central intervals.

A simple practical rule for finding the buoyancy of a cask is to multiply the number of gallons it contains by 10, which gives a result in lbs. a little less than the actual buoyancy.

The buoyancy of timber, &c., for rafts will be found by calculating its cubic contents and deducting the weight of the material from that of the water displaced.

Anchors are required to counteract the effect of the current or wind on floating objects; the nature of holding ground, and the strain on the cables, regulate their size. To ensure holding, the length of the cables should be 10 times the depth of the stream, and in no case less than 30 yards. When the length is less than three times the depth, the anchors seldom hold.

An improvised anchor may be made of pickaxes lashed together, of bent iron bars, or of wicker cases filled with stones.

Portable Bridge Equipments.

The portable bridge-equipment, which forms part of the *matériel* requisite for every field force, usually comprises two forms of bridge-construction capable of being used either separately or in combination, viz., pontoon bridges and trestle bridges; the first forming a floating and the second a fixed bridge.

Complete bridges can only be constructed of pontoons alone across channels, when there is water at either bank, sufficient at all times to float the pontoons, a condition not usually obtainable in waters subject to rise and fall of tide, or to sudden changes of depth, due to floods from falls of rain, &c.

It follows, therefore, that even for crossing rivers, the bridge-equipment can rarely be confined to pontoons, and there are, of course, cases where the military communications may have to be rapidly completed over gaps where a pontoon cannot be used at all. An equipment of fixed supports (usually trestles) is in such a case a necessity.

As the pontoon and trestle equipment, which accompany the advance of an army, are usually required to be moved along with the divisions to which they are attached, they have frequently to be replaced by other non-portable bridges made out of such material as can be most conveniently procured.

In such cases, rapidity of construction, with a view to set free the portable equipment, and fertility of resource in turning to the best account the materials at hand, should mark the military bridge-constructor.

To give effect successfully to these requirements, the directing officer should be thoroughly trained to bridge-construction. He should endeavour, by a proper distribution of men and material, rapidly to construct his bridge of the required strength; questions of appearance, economy of material, and permanency being of secondary consideration.

In the Journal of this Institution,[1] will be found carefully prepared papers, giving detailed particulars of the pontoons and trestles used in the bridge-equipments of the chief continental armies, and those which were in use in the British Service up to the year 1870. In these papers, the merits and demerits of the pontoons described, are minutely entered into. The subject was then of considerable interest, as a change in the nature of our own bridge-equipment was deemed necessary, and there was naturally much discussion as to what the new pattern should be.

After much consideration and practical trial, the pontoon (Plate XL.) was adopted for the British Service.

Attention is also directed to the German pontoon (Plate XLI.), which has, of all foreign models, been that most largely and successfully used in late wars.

Pontoons.

A pontoon should fulfil the following conditions:—

1. It should be capable of sustaining the greatest load liable to come over it while in bridge.
2. It should be as portable and light as consistent with the first condition, and with the capability of standing the rough usage to which it would be subject on active service.
3. The pontoon, with its corresponding superstructure, should be of such a form as to admit convenient stowage in wagons, and of being easily converted into a bridge, and of being rapidly moved with the advance of an army.
4. It should be of a form and material that admit of a ready examination and of being easily repaired, and it should not be liable to damage or leakage from alternate exposure to wet and heat.
5. Wagon loads should be complete in themselves, and the parts of the equipment should be interchangeable.
6. The pontoon should be capable of being used as a boat.

Austria.

The Austrian pontoon and trestle equipment is fully described by Colonel Lovell in vol. ix, pages 42—46 of the Journal of this Institution.

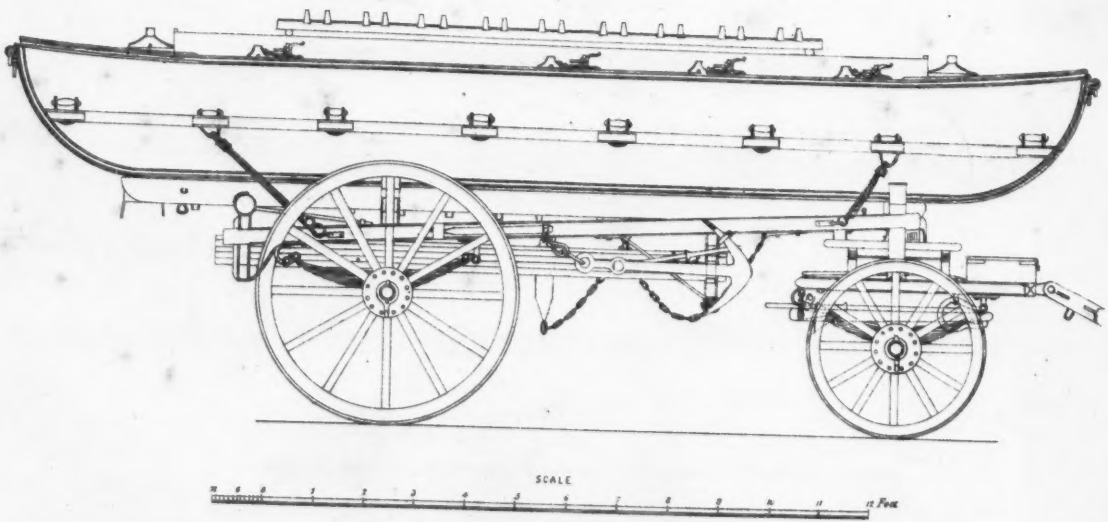
The pontoons are formed in sections, and in making bridges, two, three, or four of these sections are used according to the degree of buoyancy required in the supports. Supports made of two sections are supposed to meet ordinary requirements.

Single sections may be used for narrow infantry foot bridges. Owing to the size of the pontoons, and the distance at which they are placed apart, some of the superstructure of the equipment is clumsy and not easily handled.

The trestles used in the Austrian pontoon equipment (see Plate IX., page 44, vol. ix), are two-legged, usually called "Birago trestles" (after General Birago, by whom the Austrian equipment was devised), and are of the kind most largely used in the bridge-equipments pre-

[1] Vol. iv., pp. 237, et seq; and vol. ix., pp. 29, et seq.

BRITISH PONTOON LOADED ON WAGON.



Papyrotype. S.M.E.

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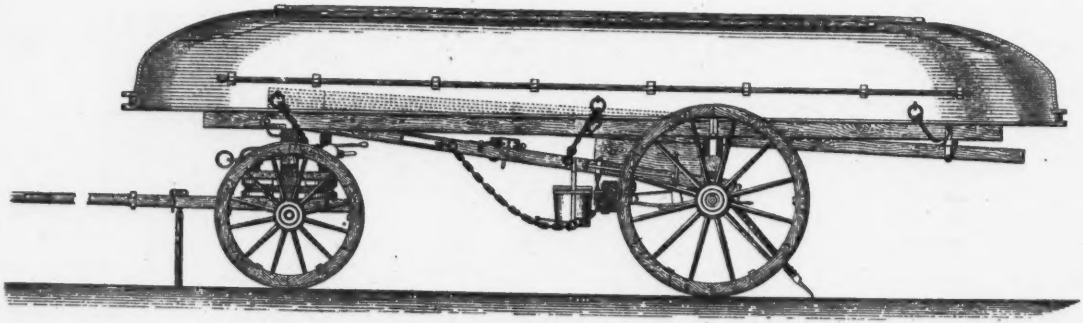
PL. XL

GERMAN PONTOON LOADED ON WAGON.



Papyrotype. S.M.E.

pared to accompany Army Corps. They are easy of transport, and when the bed of the river is fairly solid, and the depth and current of the water not great, they make a good bridge for field troops. Their stability, not at any time as great as could be desired, depends on the cleated baulks which connect them with the shore.

Each trestle is provided with three sets of legs to suit various depths of water.

Their great disadvantage is, that if, on account of alteration in the depth of water due to rise and fall of tide, or other causes, it becomes necessary to alter the level of the bridge in deep water, this cannot always be done without stopping all traffic, and without considerable subsequent delay in re-adjusting the heights of the cross-pieces (transoms) which support the roadway.

A section of the bridge-train consists of 14 wagons, each carrying part of a pontoon, and provides supports and superstructure for 168 feet of bridge. There are 40 such sections = 6,720 feet = 2,900 yards of bridge, and 8 more in reserve.

During the year 1873, pontooning operations took place near Linz, at which point the River Danube is about 280 yards wide, and the current very rapid, in some cases as much as five miles an hour.

The number of men employed to construct a bridge varied, and amounted to from 300 to 400 men, including Non-commissioned Officers. The time occupied was from 3 to $1\frac{1}{2}$ hours, the minimum time being when the work was done in the presence of the Emperor.

Openings were made in the bridge to admit of the passage of steamers, &c., the average time taken to make the opening was about 10 minutes, and to close it 14 minutes.

By night the bridge was put together in $2\frac{1}{2}$ hours, about one-half the length having been formed by day and brought into position by night.

Large numbers of troops were, during the operations, ferried across the river in pontoons.

Belgium.

The Belgians have a pontoon-train-equipment for about 260 yards of bridge.

The pontoon and trestle-equipment are very fully described by Colonel Lovell, pages 49, 50, vol. ix.

The trestles are three-legged, and of a construction which admits of the adjustment of the legs to suit uneven ground. Their great advantages are, stability and facility for altering the level of the bridge during rise and fall of tide. They are more difficult to place in deep water than two-legged trestles, but when placed, they are safer.

The shape of the pontoons has been worked out with great care, and they possess, in a high degree, many of the elements of a good pontoon.

Their weight, 1,200 lbs., is, however, greater than appears admissible for a train which is to keep up when necessary with the advance of an Army.

France.

The French Bridge-Equipment, as approved in 1853, and still used, comprises 4 divisions and 1 reserve. The equipment is composed of open wooden boat pontoons, light boats, and trestles (2 legged). The proportion in each division of pontoon-train consists of 8 pontoons, 2 trestles and 1 light boat.

This is sufficient for 58 yards of bridge without using the trestles, and 70 yards using the trestles.

The complete equipage is sufficient for about 215 yards of bridge without using trestles, and 265 yards if trestles are used.

The French pontoon train was largely used in the campaign of 1859; and after the experience of that campaign, it was stated that the regulation bridge-equipment, while well adapted as a reserve for the passage of large rivers, did not possess the mobility necessary to enable it to follow the movements of the Army divisions, or to render all the services expected of it in a country intersected by numerous watercourses of medium size.

A lighter equipment has been under trial, but I learn that it has not yet been adopted.

Holland.

The Dutch pontoon train consists of 2 companies and a depôt. One company is organized to accompany a field force, and consists of 3 officers, 21 non-commissioned officers, and 175 men.

The pontoon is an open flat-bottomed wooden boat, with flat sloping ends. Length, 26 feet. Weight about 1,250 lbs.

It is, like the French pontoon, too heavy to be carried on the same wagon with its superstructure, and the introduction of an improved pattern is contemplated.

The number of pontoons (30) is sufficient for 220 yards of bridge.

The trestles used are of the Belgian pattern. Eight are carried, sufficient for 28 yards of bridge.

Total bridge train, nearly 250 yards.

Pontooning operations take place annually at Dordrecht, where the river is about 150 yards wide, the rise and fall of tide being about $4\frac{1}{2}$ feet.

The Dutch Army being a militia force, the time allowed for training their pontooneers is very short.

Russia.

The Russian bridge-trains are composed of half a battalion (two companies) of pontooneers to each Army Corps. Each company consists of 200 non-commissioned officers and men including 60 drivers. Each half battalion has 26 iron pontoons in two compartments (carried on 52 waggons) and 12 trestles, and the equipment is sufficient to form a bridge 260 yards in length.

The Russian pontoon is in form and size very similar to the Austrian, and the superstructure is of the same kind.

The trestles also resemble the Austrian bridge pattern.

Germany.

The new pattern German pontoons are of iron; an old pattern of the same shape is of wood, and is now used for reserve equipments. The pontoon has similar boat-shaped ends, is not decked, and the material not being buoyant, it is liable to sink in case of accidental damage. (Plate XLI.)

Its weight is about 950 lbs., and its available buoyancy is from 9,000 lbs. to 10,000 lbs.

Used singly, the pontoons do not make safe boats for a number of men, but whether used as boats, or in bridge, they offer, from their shape, less resistance to wind and current than pontoons with square ends.

The pontoons, as well as the superstructure, are of simple form, they can be placed in bridge at any desired interval apart, and are readily adapted to the varied conditions under which a portable bridge-equipment may have to be used.

Since the last war, the arrangements for the manning and equipment of the German Pontoon Corps have been modified, and the system previously in force of having only the company for each army corps trained as pontooneers, has been abandoned.

Every company of the engineer force liable to take the field, is now trained to undertake bridging operations, and in place of heavy and light bridge-trains, all bridge-trains are alike, and capable of being used together.

Under the Regulations, date 1874, now in force, each army division has a divisional bridge-equipment, composed of 6 pontoons and 4 trestles, sufficient for 43 yards of bridge, and each army corps has in addition a corps equipment of 24 pontoons and 2 trestles sufficient for 146 yards of bridge. Total for each army corps, 232 yards of bridge.

This equipment is always in charge of the officers and companies told off to move with it on service in the field, and they use it (when required) for their annual practice, and keep it in repair.

In addition to this equipment which appertains to the army corps, there is a certain small amount of bridge material allowed for instructional practice; there are also, in charge of the engineer troops quartered in the fortresses on important rivers, such as the Rhine and Elbe, reserve equipments for service in those rivers, the amount being what is considered sufficient for any special bridge likely to be required.

It will thus be seen that, as the result of their experience during the late war, the Germans have increased their cadres of bridge-constructors, and simplified their equipment with a view to obtaining greater bridging resources.

In addition to the regular bridging-exercises of the German engineer troops, whose head-quarters are always fixed at some fortress

on a river so that they may have constant practice in bridge-construction, pontooning operations on a large scale take place periodically on one of their more important rivers.

Last year these operations took place on the Southern Elbe at Harburg, and a short account of them may be of some interest.

The operations were carried out between July 20th and August 15th, 1874, in accordance with a programme which had been prepared some months beforehand, and a sum of money was placed at the disposal of the Directing Officer (Colonel Crüger), to defray all attendant expenses.

The troops taking part in them were 2 companies of pioneers from each of 4 Army Corps (Guards, 4th, 9th, 10th), and one company from the 3rd Army Corps. Total 27 officers and about 800 non-commissioned officers and men.

A Captain or senior Lieutenant from every pioneer battalion not represented by companies, was also ordered to attend the operations.

The Elbe, at the point selected for the practice, was from 370 to 400 yards wide.

The material used in making the bridges was the bridge-equipment of the 3rd, 4th, and 9th Army Corps, the Elbe Reserve, and the instructional *matériel* of the 4th and 9th Pioneer battalions.

This was sufficient to enable two bridges, total length about 750 yards, to be constructed daily at two separate bridging grounds about 1,200 yards apart.

The exercises were carried out for five days in each week, and various modes of constructing bridges were practised, both by day and night.

On each occasion, bridges complete in all respects were formed, and cuts for the passage of boats and barges were opened and closed.

The work was essentially practical and instructive.

Among the more noticeable operations were :—

The construction of a bridge 370 yards long, in a very dark night in less than two hours. The work was carried out so quietly that noise could not be heard a few hundred yards off.

On another occasion, the programme was to convey the materials in rafts some three miles down the river, and to form a bridge at a site indicated.

The spot selected was near Sandau.

The river here has a breadth of 400 yards, and a smaller arm had also to be bridged over in order to complete the communication, its breadth being 140 yards.

It was ordered that the material should be formed into rafts of four pontoons, and be brought up on the morning of the 6th, so as to reach the bridging ground at 7 A.M. In order to do this, some of the men had to leave their cantonments soon after 3 A.M. The rafts left the bridging ground at Harburg at 5 A.M., and at the appointed time, the bridge was commenced by placing some trestles.

During the forenoon the wind rose and blew a gale and the tide rose abnormally. It was, in consequence, found necessary to raise the trestles, which was a difficult operation and took some hours. The

rafts could not be brought into their position in bridge against the tide and wind by rowing, and had to be warped up one by one. This caused further delay, and it was 3.30 P.M. before the bridge was completed during a storm of wind and rain of great violence.

After a rest of less than an hour, the bridge was dismantled, but owing to a further rise in the level of the river, and consequent overflowing of the river banks, there was a delay in securing the material, and it was 11 P.M. before some of the men got back to their cantonments.

The next morning they were at work at the usual hour, 6 A.M.

The battalion of infantry quartered at Harburg, was, on another occasion, conveyed across the river in small transport rafts, in the presence of His Excellency Lieutenant-General von Treskow, commanding the 9th Army Corps.

To conclude the operations, the bridge-material was formed into large transport rafts, consisting in one case of as many as 48 boats, which were towed by steamers and formed into bridges (one over 500 yards long), at different points on the Elbe, the troops going into bivouac on the river banks.

These final operations were performed in the presence of three Inspecting Generals of Engineers who came from Berlin for the purpose.

I was much struck with the quiet demeanour and the good discipline of men, few of whom had two years' service.

The satisfactory manner in which the work was done, appeared to be in no small degree due to the constant and zealous supervision of the officers of the companies.

England.

The British new pattern pontoon is a boat with similar decked ends, and is partly decked at the sides. (Plate XL.)

The extreme length is 21 feet 7 inches, its extreme breadth is 5 feet 3 inches, and its depth amidships, including the coamings is 2 feet 8 inches.

The pontoon weighs about 800 lbs., and draws, when floating empty, $2\frac{1}{2}$ inches, and when in bridge, 6 inches. Roughly speaking, every inch of immersion, gives 500 lbs. of buoyancy. The space between two pontoons, in bridge, is always 15 feet, and at this interval, the buoyancy of the pontoon is sufficient to admit of the passage of siege artillery.

The boats consist of a timber framework covered with wood and canvas, put together with a solution of india-rubber.

It is sometimes known as "Clarkson's Material," but differs from the latter in the omission of cork and leather, which were used in the original samples.

Trestles are also carried in the British pontoon train, but the pattern has not yet been finally decided on.

Various expedients have been tried with more or less success, for getting over the defect already mentioned in the two-legged (Birago)

trestles, which otherwise are decidedly the favourites with officers commanding pontoon companies.

The impression left on my mind by the trials which took place at Harburg last year, is:—

That we should have in our equipment, trestles capable of being used either as two-legged, or as tripod trestles, as circumstances might require, and trestles of this kind, of which I produce a model, are now being experimentally made at the School of Military Engineering.

The weight of a composite trestle will about equal that of a pontoon.

A unit of pontoon train consists of one troop of Royal Engineers, provided with—

20 pontoon wagons, loaded with pontoons.
4 ,, ,, ,, trestles and superstructure.

The unit (only one is equipped) is sufficient for 100 yards of floating, and 20 yards of trestle bridge.

This does not exceed half the proportion allotted to a single German Army Corps.

Our regular pontoon-train consists of a single troop of Royal Engineers, which is trained in bridging and nothing else; but all the Royal Engineer recruits are instructed in bridging-operations.

So far as the nature of equipment goes, ours is, I think, second to none, if not superior to all, in general fitness for field-service.

The quantity kept in readiness for field-service is, however, very small, and including the reserves in store, for which no men nor horses are set apart, is not sufficient to cross more than one river of ordinary width. The whole equipment, reserves and all, would not cross the Thames at Westminster Bridge, and the Thames at this point is some 50 to 70 yards less wide than the Elbe at Harburg. There two complete bridges were constructed daily.

Our arrangements for annual practice have as yet been incomplete, our pontooning has taken place either in narrow channels of still or comparatively still water, or in the case of those in the Medway, we have not as yet had sufficient equipment of the regulated patterns to make a complete bridge across the river at our practice ground.

The practice, moreover, is very much interrupted and attended with risk, in consequence of the constant passage of barges, which are subject to no special obligation to keep clear of the bridges, and in some cases are only too glad of an excuse for running them down.

For very light infantry bridges, there is not at present any recognised equipment in our service. The want is one which it is very desirable to supply, and the subject is now under consideration. Some infantry pontoons of the type of the old pattern Blanshard Pontoon are in existence, and were found very useful in the Gold Coast Expedition, but they cannot be used singly as boats, and do not supply light troops moving over ground intersected with canals or narrow watercourses, with convenient means of crossing such obstacles.

The late Captain Fowke, R.E. (whose lecture on pontoons at this Institution in 1860,[1] attracted much attention), proposed to supply this

[1] See Journal, Vol. IV., p. 237, *et seq.*

want by collapsing canvas pontoons such as shown in the model, and in certain cases these pontoons, which are very light and portable (total weight of pontoon and superstructure being about 60 lbs.) would be very useful.

Some pontoons of this pattern were sent to the Gold Coast, but they were destroyed by ants and rats before use could be made of them.

The material is therefore unsuited in such a climate.

I have, within the last few days, tried a few light pontoons of the form indicated in the model, designed by Lieutenant Elliot Wood, R.E. These boats used singly, and connected by light ladders, which for telegraph and other purposes are essential for engineer-equipments, promise to provide a safe and steady bridge for infantry in single rank.

Two boats lashed together will form a safe pier for infantry in file and light artillery passed over by hand.

The weight of each pontoon will be about 70 lbs., and of the ladders about 35 lbs. each.

I propose that one boat and two ladders, with a proportion of plank 1½ cwt. in all, shall be carried in each wagon allotted for engineer-equipment.

This will provide means of crossing a watercourse about 18 feet in width.

Trussed girders of the form proposed by Major-General Bainbrigge, R.E., and supplied to the Gold Coast Expedition, and successfully used for connecting some of the piers of the Prah Bridge, would be very useful for passing men or guns over gaps up to 30 feet in width.

The weight of a single girder with roadway 15 inches wide is about 400 lbs. No part exceeds 11 feet in length, or 46 lbs. in weight, so that they are easily packed and carried.

Three 3-inch planks, 12 inches wide and 10 feet long, connected and trussed on the same plan answer equally well, and require less fitting and workmanship. The total weight is about 350 lbs. Of this, the planks weigh 80 lbs. each, 240 lbs. in all. The tension rods and connecting plates, &c., together, weigh about 110 lbs.

Ladders strengthened in the same way would also be useful.

I wish here to state that although for the safe, careful and scientific application of the principles of "bridge-construction" a considerable amount of technical knowledge and experience, which it is the peculiar province of an engineer to acquire, is requisite, yet the subject is of general interest, because the regulations of our service wisely lay down that all Officers, non-commissioned Officers, and men of infantry corps are to have a certain, though limited, amount of practical instruction in field-engineering, including the formation of improvised bridges of simple type.

When I was invited by the Council of this Institution to give a lecture "on Military Bridge-Construction as practised abroad," I replied that I considered it would be more interesting if I were also to say something of what is being done at home, and the Council were

good enough to accede to this proposal. I have good reason to believe that in no other nation have the means of instructing the Army at large in field engineering works, been more carefully provided for by the authorities than in our own; but I believe that if contingencies should unfortunately arise to bring our Army into collision with the standing Army of one of the Continental powers, the proportion of trained troops in the engineer branch of our service would, in the absence of any reserve liable to service out of this island, be totally inadequate to meet the demands which would be made on the corps. To provide therefore for such a contingency, every opportunity should be taken of requiring and encouraging the exercise of troops of all arms in simple practical field engineering operations, and of these none are more important than "military bridge-construction."

Owing, I apprehend, to the small number of drilled soldiers in our battalions, and to the many necessary duties and detachments, the number who have received this limited training is not as large as it would have been desirable to instruct.

It is, at the same time, necessary to guard against the tendency to count men twice over by assuming that, because they can be made useful in more than one capacity, they will, in time of war, be available for both.

I have great pleasure in testifying to the interest taken in military bridge-construction by the numerous Officers of all ranks, and non-commissioned Officers and men to whom opportunities of being instructed therein have been afforded at the School of Military Engineering.

Some of these Officers who had previously qualified for Staff employment have informed me, that they attached great value to the practical experience incident to the courses at the School of Military Engineering.

There is no doubt that the opportunities given to Officers of all arms, and especially to candidates for Staff employments of making themselves acquainted with the duties and capabilities of sister services, has, in no small degree, tended to raise the attainments of British Staff Officers to their present high standard.

It is more than ever necessary that Officers in command of mixed forces and Staff Officers should be capable of quickly appreciating the part that should be assigned to each arm in tactical combinations, and by a judicious application of the auxiliary arms, be capable of giving full effect to the offensive power of the *infantry*, on whom in recent, as in all former wars, the brunt of the fighting has fallen.

While advocating greater attention to the training of the troops in military engineering works, I wish to guard against the possible deduction that I consider this instruction should be necessarily imparted at the school with which I am connected, or at any other special school.

I am, on the contrary, of opinion that provided the regimental and company Officers and non-commissioned Officers are, as they should be, competent, instruction is best afforded to the men by those likely to be associated with them on service in the field.

I therefore consider that in this particular matter, the engineering practice of each army division ought to be conducted with the assist-

ance of the engineer troops and equipments which form part of that division, and that the operations of the military schools should be more especially directed to training the Officers and non-commissioned Officers, who are afterwards to act as instructors in their regiments and companies, and the candidates for Staff employment. I am also strongly of opinion that it should be our endeavour to assign to each military corps, duties on the efficient performance of which, their credit should depend, and that in our army there should be a division of labour, corresponding to that which, in the commercial enterprises of this nation, has produced results, *successful*, beyond parallel.

APPENDIX.—*Bridges constructed by the German Army*, 1870.

No.	Name of River.	Site.	Date of Construction.	Date of Demolition.	Length in mètres.	Description of Bridge and *Matériel* used.	Remarks.
			1870.				
1	Saar ..	Mettlach	Aug. 3.			Pontoon equipment.	
2	„ ..	Schweig.....	„ 3.	.. ..	100	Scratch materials.	
3	„ ..	Berncastel.....	„ 4.	.. ..	100	„ „	
4	Sauer ..	Spachbach.....	„ 5.	.. ..	.. ..	Foot bridge. Hop poles.	Eight bridges made here.
5	„ ..	Woerth	„ 5.	.. ..	.. ..	Scratch materials.	Five bridges made here.
6	Nied ..	Etarges	„ 12	.. ..	.. ..	„ „	Four bridges made here.
7	„ ..	Parge.....	„ 12	.. ..	.. ..	„ „	Two „ „ „
8	„ ..	Courcelles	„ 12	.. ..	.. ..	„ „	Three „ „ „
9	Moselle	Pont a Mousson.....	„ 13	.. ..	.. ..	Floating and trestles. Pontoon equipment and scratch materials.	
10	„	Champy.....	„ 13	.. ..	86	Foot bridge. Pontoon equipment.	Afterwards made practicable for waggons.
11	„	La Lobe.....	„ 16	.. ..	.. ..	Pontoon equipment	
12	„	Poncé ferme	„ 16	.. ..	.. ..	„ „	
13	„	La Lobe Poste	„ 17	.. ..	80	17 trestles. Scratch materials.	
14	„	Arry.....	„ 17	.. ..	.. ..	Pontoon equipment.	
15	„	Corny.....	„ 17	.. ..	.. ..	„ „	
16	Meuse..	Charny	„ 30	.. ..	.. ..	„ „	Two bridges made here.
17	„ ..	Donchery.....	„ 30	.. ..	45	and scratch materials.	Two bridges made here.
18	„ ..	Nouvion	Sept. 1.	.. ..	60	Pontoon equipment.	
19	„ ..	Sedan.....	„ 1	.. ..	64	Pontoon equipment	Two bridges made here.
20	„ ..	Bazeilles	„ 2	.. ..	.. ..	Foot bridges. Scratch materials.	5 tree bridges over small streams.

No.	Name of River.	Site.	Date of Construction.	Date of Demolition.	Length in mètres.	Description of Bridge and *Matériel* used.	Remarks.
			1870.				
21	Marne .	Trilport.....	Sept. 13	Nov. 26....	114	Pontoon equipment and scratch materials.	
22	Seine ..	Corbeil.....	„ 17	Sept. 23....	136	14 pontoons, 6 trestles....	A party of Infantry was ferried across in pontoons.
23	„ ..	Villeneuve St. Georges .	„ 17	„ 19....	135	27 pontoons and 2 trestles	Partly constructed under musketry fire.
24	„ ..	„ „ „ .	„ 18	„ 30....	136	29 pontoons.....	The cables had to be protected against ice.
25	„ ..	Corbeil.....	„ 18	Dec. 26, broken by floating ice.	128	13 trestles, 25 afterwards added. Scratch materials.	This bridge represented 4,000 hours' work. It was raised 0·55 mètres and the trestles doubled. Loaded with 240 rails.
26	Marne .	Lagny	„ 18	Sept. 19....		9 pontoons.	
27	Oise ..	Pontoise.....	„ 18	„ 19....	79	13 pontoons and 3 trestles.	This bridge was constructed in 2 hours for the passage of 5th and 6th Divisions of Cavalry.
28	Seine ..	Corbeil.....	„ 19	Dec. 24, broken by floating ice.	101	14 trestles. Scratch marials.	Raised and repaired in November.
29	„ ..	Choisy-le-Roi	„ 19	Sept. 30.. ..	75	Flying bridge. Pontoon equipment.	Carried 60 men in 4 to 5 minutes, including time for embarking and disembarking.
30	Marne .	Gournay	„ 19	Nov. 8.....	72	Pontoon equipment. Replaced by improvised trestle bridge, and remade on November 9th with pontoons.	

No.	Name of River.	Site.	Date of Construction.	Date of Demolition.	Length in mètres.	Description of Bridge and *Matériel* used.	Remarks.
			1870.				
31	Seine ..	Triel	Sept. 20	Sept. 21....	126	18 pontoons and 7 trestles. Pontoon equipment.	This bridge was constructed in 1½ hours, during the night, and cavalry ferried across on September 19th.
32	„ ..	Les Tamerics	„ 20	Jan. 29	177	31 pontoons and 7 trestles. Pontoon equipment.	Raised 3 mètres on account of high tides. Swung 23 days on account of ice.
33	Marne .	Pomponne.....	„ 21	Nov. 26	68	Pontoon equipment of the vanguard and 5 barges of the Marne.	Constructed in 10 hours. Pontoons successively replaced by barges. Dismantled for one day.
34	Seine ..	Orly.....	„ 23	Oct. 31, dismantled during a high tide.	.. ..	Pontoon equipment of Prussians and Wurtemburgians.	While the bridge was being swung, a flying bridge was used.
35	Oise ..	Beaumont	„ 29	Oct. 4.....	81	16 pontoons, 1 trestle. Pontoon equipment.	Constructed for the expedition against Franco-Tireurs.
36	Seine ..	Villeneuve St. Georges .	„ 30	Dec. 24	165	50 pontoons in rafts of 6. Double road.	
37	„ ..	„ „ „ .	Oct. 1..	Oct. 17	90	8 pontoons and 7 trestles.	
38	„ ..	Choisy-le-Roi	„ 2..	„ 21, dismantled during a high tide.	116	Foot bridge. Scratch materials.	
39	Oise ..	Beaumont	„ 4..	.. ..	23	3 trestles 7 mètres high. Scratch materials.	Permanent bridge repaired; destroyed by the French.
40	Seine ..	Villeneuve St. Georges .	„ 7..	Dec. 24	112	32 piles, with sleepers at the bottom. Scratch materials.	The superstructure was injured, owing to its low level. The levels of the roads leading to the bridge were too low.

No.	Name of River.	Site.	Date of Construction.	Date of Demolition.	Length in mètres.	Description of Bridge and *Matériel* used.	Remarks.
			1870.				
41	Seine ..	Villeneuve St. Georges .	Oct. 12.	Dec. 24	155	22 piles. Scratch materials.	Piles were driven 2.30 mètres deep with pile-drivers mounted on rafts. Each pile took 150 hours of work, and the superstructure was 2.70 above water-level. The bridge was loaded with rails.
42	Loiret..	Olivet.....	„ 14.	.. ..	.. ..	.. ..	Substantial bridge repaired.
43	Oise ..	Pontoise	„ 21.	Oct. 25.....	82	14 pontoons and 3 trestles. Pontoon equipment.	Trestles placed between the regular trestles.
44	„ ..	„	„ 21.	„ 21.....	21	4 trestles. Scratch materials.	Permanent bridge repaired.
45	Loire ..	Toury	„ 25.	.. ..	330	Scratch materials	Afterwards lengthened to 375 mètres.
46	Seine ..	Orly.....	„ 30.	Nov. 3	148	21 trestles. Pontoon equipment.	As a flood was expected the flooring was much elevated.
47	„ ..	„	Nov. 1.	.. ..	.. ..	Piles. Scratch materials.	Not completed.
48	„ ..	Corbeil.....	„ 4.	Dec. 1.....	130	21 pontoons, 2 trestles. Pontoon equipment.	
49	„ ..	Orly.....	„ 8.	„ 3.....	.. ..	Flying bridge. Pontoon equipment.	Similar to No. 29.
50	Marne .	Chelles.....	„ 8.	Nov. 9.....	.. ..	Flying bridge	Substitute for No. 30.
51	„ .	Gournay	„ 12.	.. ..	80	12 piles. Scratch materials.	Flooring elevated 3 mètres above water-level.
52	„ .	Lagny	„ 13.	.. ..	70	5 piles and 7 trestles. Scratch materials.	
53	„ .	Gournay	„ 19.	Dec. 6.....	98	Pontoon equipment and scratch materials.	Dismantled because it was under enemy's fire.

No.	Name of River.	Site.	Date of Construction.	Date of Demolition.	Length in mètres.	Description of Bridge and *Matériel* used.	Remarks.
			1870.				
54	Seine ..	Juvisy	Nov. 12.	Dec. 24, by floating ice.	156	31 pontoons, 1 trestle. Pontoon equipment.	
55	Marne .	Noisel	Dec. 6	Jan. 29.....	87	10 pontoons, 2 trestles. Pontoon equipment.	
56	„ .	Lagny	„ 6.	.. ..	85	Scratch materials.	
57	Loire ..	Gien.....	„ 8.	.. ..		Flying bridge. Scratch materials.	The continuations on the banks were 35 mètres long.
58	„ ..	Blois	„ 10.	Dec. 12...		Piles and boats. Scratch materials.	
59	„ ..	Beaugency.....	„ 11.	„ 13.....	240	Pontoon equipment	Constructed in 10 hours, but the bridge itself only occupied 4 hours.
60	„ ..	Saint Dié.....	„ 13.	.. ..		„ „	No. 59 repaired.
61	„ ..	„ „	„ 14.	.. ..	320	„ „	There is an island here. The bridge from the right bank to the island was made by Prussians, from the left bank to the island by Bavarians.
62	„ ..	Blois.....	„ 15.	.. ..	22	Scratch materials	No. 58 restored. Hessian troops were ferried across in pontoons.
63	Marne .	Between Vaires and Noisel.	„ 19.	Jan. 28.....	109	Prussian and Saxon pontoon equipment.	Dismantled for a few days on account of ice.
64	Loire ..	Orleans	„ 23.				
65	Seine ..	Villeneuve St. Georges .	„ 27.	Jan. 19.....	.. ..	Bridge on the ice. Pontoon equipment.	The level of the ice was artificially raised and the surface roughened.

Evening Meeting.

Monday, June 7th, 1875.

ADMIRAL SIR HENRY J. CODRINGTON, K.C.B., in the Chair.

METHODS OF ASCERTAINING THE RELATIVE VALUE OF COALS FOR NAVAL PURPOSES.

By E. ECKERSLEY, Esq., Chief Engineer, R.N.

COAL is a substance which during modern times has played a very prominent part in the naval and commercial history of the world; and taking into consideration the amount exported from these shores, I think I may fairly assert,—that from our coal mines is drawn the greater portion of that fuel which is the real motive power of the steam-engine.

Officers are sometimes placed in positions in which it would be beneficial if they could form a just estimate between different qualities of coal. This is my excuse for attempting to describe a few of the methods by which scientific men approach this subject; coupled with my own practical experience and observation.

So many eminent men of science have written upon the subject, What is coal? that I could hardly take up your time in giving a detailed account of their various theories.

All are agreed upon this one point, that coal is of vegetable origin; and the greater portion consider it but the decomposed remains of a luxurious vegetation which this country possessed at a distant period. This being so, you can understand with what rapidity, ferns, lichens, rushes, and such like plants grew; the air then containing more carbonic acid—"now about four parts in ten thousand"—more moisture, and the heat more intense.

In the spring these plants increased enormously, but as winter approached numbers died; the next year they were succeeded by others, quantities of which in their turn also died, and so were produced layer upon layer; the whole eventually becoming covered with earth, by the streams carrying it down the hill sides, or by a sudden upheaval, and in time we find this vegetable substance, changed to the different

forms we now see it in; namely peat, lignite, bituminous and anthracite coal.

The following table will give you some idea of how these substances differ, and by its means we are enabled to form some estimate of its action through different stages.

By keeping the amount of carbon up to 100 we have,—

	C.	H.	O.
Wood	100	12·18	83·07
Peat	100	9·85	55·66
Lignite	100	8·37	42·42
Bituminous coal	100	6·12	21·23
Anthracite	100	2·84	1·75

Thus showing that the different kinds are formed by a slow deoxidation of woody fibre.

In a paper lately read by Mr. F. A. Paget, it is asserted that a vertical peat-bog always shows different stratifications, differing very much chemically and physically. The material alternates from a nearly useless bog at the top to an amorphous bituminous peat, scarcely inferior to lignite coal. Dr. Swift states that the amount of carbon in peat is nearly double at the bottom, and in some rare cases peat is even found converted into coal, showing that peat is only fossil fuel in its early, and more recent stage.

The stowage of coal is always a matter of great importance, and depends upon its mechanical formation, as well as specific gravity. In the course of some experiments undertaken to test those which could best resist the constant friction in a ship's hold, it was found that the nearer the cleavage of the coal assumes the shape of a cube the better it was. These experiments were performed by putting different specimens in a drum, which was made to rotate for the same length of time, and the dust produced separated and weighed.

The amount of water contained in coal is a matter of serious consideration, varying, according to Dr. Percy, from 1 to 20 per cent.

If the coal had absorbed much water, and the vessel is sent into a tropical climate, the water becomes heated, and thus by its expansion causes the disintegration of the coal; and as small coal is not so valuable as that of an average size, you can form some estimate of that loss.

But there is another reason, and one which is not so likely to strike you. To illustrate this, I will suppose a case which is likely to occur in actual practice.

A troop ship arrives at a port in China, and requiring to fill up with coal, has the option of several kinds. The ship stows 1,000 tons, and the different varieties vary in the amount of water contained, from 1 to 6 per cent. Thus in 1,000 tons of the former kind we should be purchasing 10 tons of water, whilst in the latter it would

be 60; "a difference of 50 tons;" and as the price of coal during my period of service there was nearly £4 per ton, we should by choosing that containing the greater portion of water, be paying a difference of £200 for a thing (water) which was detrimental, and which could be easily obtained over the ship's side, if wanted, without charge. Unfortunately this loss does not end here, for a certain amount of the carbon will be required to evaporate this water, without giving heat to the boiler; thus more heat is dissipated, or in other words, so much more loss.

As a proof that I am much within the average, I call your attention to a table made by Professor Whitney, on coals on the Pacific Coast.

Proximate Composition of Cretaceous Coals.

	Monte Diabolo.			Bellingham Bay, Washington Territory.	Naniamo, Vancouver's.
	Clarke & Co.	Black Diamond.	Cumberland.		
Water.....	13·47	14·69	13·84	8·37	3·98
Bituminous substances.....	40·36	33·89	40·27	33·26	32·16
Fixed carbon.....	40·65	46·84	44·92	45·69	46·31
Ash.....	5·52	4·58	0·97	12·68	18·55

To make it still more striking, I may quote the case of a lignite from Bovey, Devonshire, where 34·66 per cent. of water was found in the analysis.

This proves that there must be a great variation in the amount of water contained in coal; the method by which we may ascertain this amount is simple.

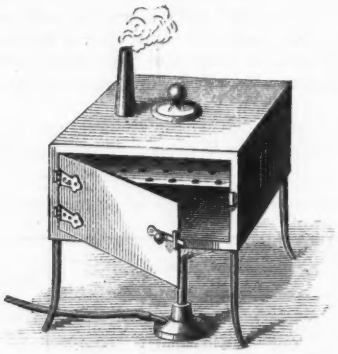
Clean and heat to redness a porcelain crucible; allow it to cool under a bell-jar, and then weigh accurately on a balance;—the more sensitive the balance is the better;—chemists generally use one which is capable of weighing to the $\frac{1}{1000}$ of a gramme (·015 of a grain). Introduce into the crucible from one to two grammes of finely powdered coal; again weigh, the difference between this and the previous weighing represents the amount of coal used.

Place the crucible, with its cover removed, in a water-oven similar to the one you see before you (Fig. 1), or expose it to a temperature of 212° F.; let it remain exposed to this temperature for at least two hours, then allow it to cool under a glass or bell-jar by the side of sulphuric acid, and again weigh.

After weighing, return the crucible to the water-oven, and expose for another half-hour; if at the end of this time, the weight is the same as before, the loss which the coal has undergone represents the moisture contained in it; if the weighing is still lighter, then it must be again placed in the water-oven, until two weighings, at intervals of

not less than half an hour, coincide; from the result obtained calculate the percentage.

Fig. 1.

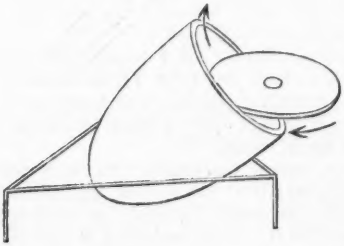


Water-oven.

Practically one of these water-ovens can easily be made on board a steam-vessel, so there will be little difficulty in estimating the amount of water. Within the past month I took some coal out of a cellar at the Royal Naval College which had been saturated; and, after remaining in the laboratory over one week, and having become to all appearance dry, was found, when analysed, to contain 15·4 per cent. of water.

Ash.—It is the general custom to call that ash which passes through the fire bars of a furnace; and, in steam-vessels, it is thrown overboard; but, as this generally contains much valuable fuel, it would hardly be considered a scientific solution of the question—How much ash the coal contained? I am afraid the limited capacity of our boiler-power has much to do with making large quantities of so-called ash on our ships-of-war, when under full steam.

Fig. 2.



To obtain this quantity, you weigh in a crucible about a gramme of coal, in a similar manner, to that for obtaining the moisture. The crucible with the coal in it, is, instead of being exposed in a water-oven, supported on a triangle above a Bunsen's burner, the flame of which must be exceedingly small at the commencement; the cover of the crucible is to remain on, only as the coal becomes heated, gas and smoke will be observed to issue from the crucible, the evolution of which must be carefully moderated so as not to carry away any of the solid particles; as the gas and smoke become clear, the heat may be gradually increased, until the whole crucible becomes red-hot; the lid should then be removed and placed in this position, Fig. (2), in order to produce a current of air in the coal, and, by this means, to burn up the carbon. The coal should occasionally be stirred with a platinum wire, and the operation of heating is to be continued until the ash of the coal is of an uniform grey, or reddish appearance, and red-hot throughout. When this is the case, the crucible is removed and allowed to cool under a glass jar and weighed. The difference between this weight and the weight of crucible, plus weight of coal, will give the ash obtained from the amount of coal used.

Then calculate, as before, the percentage.

The ash generally contains iron, silica, sulphur, and phosphates in various amounts. In passing, I may as well observe that the value of ashes for agricultural purposes depends upon the amount of phosphates they contain.

Iron and silica are of so little moment for our purpose, that I will not take up your time in describing them.

Sulphur.—This being a substance very detrimental to iron, at least merits some attention, and I have no hesitation in stating that it is the cause of much injury to boilers.

It is well known that if you take a stick of sulphur, you can force it through heated iron; such is the property it has of combining with certain metals.

Whilst Engineer-in-charge of Her Majesty's gunboat "Fervent," then lying at Bristol, I was much troubled with the boiler-tubes going in small holes about the size of a pin's head, thus utterly destroying them for practical use; and my time was fully occupied in replacing them by others. I consulted some of the best practical authorities, both in Bristol and elsewhere, but could not come to any satisfactory solution of this peculiar phenomenon. However, in my chemical studies I came across things of a similar nature; and, having consulted Dr. Debus, Professor of Chemistry at the Royal Naval College, upon this subject, he advised me to get some of the coal used as well as a portion of the tube. Unfortunately I could *only* obtain a small quantity of the coal, which I found to contain a large quantity of iron pyrites, and have come to the following conclusion:—

Whilst the coal was burned in the ordinary manner, without using the blast, the greater portion of the sulphurous acid escaped up the chimney, with little or no injury to the tubes; but, as soon as the blast was put on, thus causing an increased velocity in the products of combustion, particles of these pyrites were carried into, and

deposited upon the tubes, the sulphur contained in them combined with the iron, and, in course of time, the same action following, a hole was made, injuring the tube and necessitating its removal.

Since that, I have consulted some locomotive authorities, who always use an intense blast, and I find the same result has been observed with certain varieties of coal.

To ascertain the amount of sulphur which would be detrimental, it would, therefore, be necessary first to find the total amount of sulphur in the coal, then that contained in the ash, and subtract one from the other, the sulphur which remains in the ash doing no harm.

From various analyses that have been made by Regnault, Karsten, and others, it is shown that, in two Welsh coals, namely, Thomas's Merthyr and Resolven, the amount of sulphur varied from ·85 per cent. in the former, to 5·07 in the latter; this is certainly an extreme case.

The following table shows the average amount of sulphur contained in different kinds of coal, as ascertained from analyses from Dr. Lyon Playfair:—

No. of Samples.	Source.	Mean per cent.
36	Welsh	1·43
18	Newcastle	1·24
28	Lancashire	1·44
8	Scotland	1·11
7	Derbyshire	1·01

Although these differ so slightly, still, as the average amount is somewhere near 28 lbs. of sulphur in one ton of coal, it is a very serious question whether this is contained in the form of iron pyrites or calcic sulphate.

In judging this coal practically, you can form a very fair estimate of its value by its appearance, the iron pyrites showing out prominently in golden-coloured streaks.

Mr. Wills, F.C.S., in an able article on the "Residual Sulphur in "Coal-gas," states that they occur in large masses, and are then technically called coal brasses; their origin is probably due to the deoxidation of sulphate of iron by a large amount of organic matter, although, in some cases, it seems to have had an entirely extraneous origin, more so as it is found in layers or veins, and not diffused through the coal. I have placed on the table a fine specimen of this iron pyrites.

The method of ascertaining the amount is this:—Weigh out a portion of finely powdered coal, as before, on a watch-glass or in a crucible; intimately mix it with about five or six times its weight of a mixture composed of three parts of dry carbonate of soda, and four parts of nitrate of potash (caustic potash or soda may be used for the carbonate of soda).

Place an equal quantity of this mixture, minus the coal, in a silver or iron dish, and heat until fusion takes place, then gradually add the first mixture containing the coal. Keep the whole well fused for a

short time, then allow to cool, and when cool, dissolve the whole mass in water, taking care that none either of the fused mass or of the water is lost; if this should be the case, the experiment is vitiated. Then boil the mass up with water in a glass beaker, and add hydrochloric acid, *very gradually*, keeping the beaker covered with a watch glass or glass plate, and frequently stirring the mixture. When the contents exhibit a decided acid reaction, filter through a good piece of filter-paper, wash the beaker out two or three times with distilled water, pour this through the filter-paper, and finally, wash the paper itself.

The solution or filtrate so obtained must then be heated to the boiling temperature, and a solution of chloride of barium added. This will cause the solution to become turbid, viz., will throw down a precipitate of barium sulphate. This is now to be put on one side, and allowed to remain for twelve hours, until the sulphate of barium has settled. The substance must then be filtered through a piece of fine filter-paper, the beaker well washed out, as well as the precipitate, with hot, distilled water. Afterwards dry the filter containing the precipate in a water-oven, shake the precipitate carefully into a weighed crucible (this should be done on a piece of glazed paper), roll up the filter-paper, and twist a platinum wire round it, then burn the filter-paper in a flame, and add the ash to the crucible. Heat the crucible to redness, over a flame, allow to cool and again weigh; the increase of weight will give the amount of sulphate of barium obtained from the weight of coal used, from which the percentage of sulphur may easily be calculated, thus:—

Sulphate of barium = $BaSO_4$, the atomic weight of which is—

$$\begin{aligned} Ba &= 137{\cdot}5 \\ S &= 32{\cdot}0 \\ O_4 &= 64{\cdot}0 \\ \hline & 233{\cdot}5 \quad (BaSO_4) \end{aligned}$$

$$233{\cdot}5 : \text{weight of } BaSO_4 \text{ found} :: 32 : S$$

$$\text{Then as weight of coal} : S :: 100 : \text{percentage.}$$

or

$$\frac{(BaSO_4) \text{ found} \times 16 \times 100}{116 \times \text{coal taken}} = \text{percentage of S.}$$

We now come to the most valuable part of the fuel, namely, carbon; for that which contains the largest quantity, under ordinary circumstances, is the best for heating purposes.

The most practical method of testing it is that adopted by Berthier, and known as the litharge test. It consists in taking a small quantity of finely powdered coal, and mixing it with thirty times its weight of litharge (Pb. O). This is placed in a crucible, and covered over with an equal quantity of litharge. The crucible, covered and placed in a furnace, or over a Bunsen's flame, for a period of twenty minutes, or

until the gases have ceased to bubble through the covering of fused litharge.

The crucible should not be more than half full, and care should be taken not to use the flame too strong at first. A button of lead will now be found at the bottom. The crucible should then be tapped slightly, so as to throw down any globules of lead that may have remained in the fused litharge. When cold, the crucible is broken, and the button of lead carefully cleaned, and weighed.

It is generally asserted by chemists that the results so obtained fall short of what they actually should be, by an amount nearly equal to $\frac{1}{9}$.

The percentage of carbon is ascertained as follows:—Litharge contains 207 parts of lead and 16 parts of oxygen, and when subjected to the heat of a furnace, in presence of which carbon has a greater affinity for oxygen than lead, the carbon from the coal will combine with the oxygen in the litharge, and pass off as carbonic acid, leaving the lead at the bottom of the crucible in the following proportions:—For every 1 part of oxygen evaporated, 13 of lead will be formed. For every 12 parts of carbon, there will pass off 32 parts of oxygen; or 1 part of carbon mingles with 2·666 of oxygen to form carbonic acid.

Let x = quantity of oxygen taken from the litharge by the carbon in the coal. Let b = button of lead found, then $13 : 1 :: b : x$, or $\frac{b}{13} = x$; and $\frac{x}{2{\cdot}666}$ = quantity of carbon contained in the coal used. The percentage of carbon can then be ascertained.

Example.—Find the percentage of carbon in a button of lead weighing 300 grains. Coal tested 10 grains: $\frac{300 \times 16}{207} = \frac{300}{13} = 23{\cdot}07$ parts of oxygen and $\frac{23{\cdot}07}{2{\cdot}666} = 8{\cdot}65$ parts of carbon passed off for 10 parts of coal.

Therefore $10 : 100 :: 8{\cdot}65 : 86{\cdot}5$ = percentage of carbon.

This method, although admitted to be unreliable for original tests, in consequence of the difficulty of obtaining commercially pure litharge, as well as being based on the assumption that carbon is the only combustible substance in coal, is undoubtedly valuable, from its simplicity, and, in the hands of practical men, could always be used to test one coal against another—that coal producing the heaviest button of lead being the richest in carbon.

It has been found that pure carbon gives a button of lead 34·5 times its own weight; therefore if a sample of fuel gave 25 times its weight, $\frac{25}{34{\cdot}5}$ should equal the percentage of carbon when multiplied by 100.

Berthier and other experimenters have given the following table:—

Coking Dowlais coal ..	gives	31·8	times its weight of lead.	
Glamorgan	„	31·2	„	„
Newcastle	„	30·9	„	„
Wigan coal	„	28·3	„	„
Cherry coal, Derbyshire	„	27·2	„	„
Glasgow Cannel ..	„	24·9	„	„
Durham	„	31·6	„	„
Pennsylvanian anthracite	„	30·5	„	„

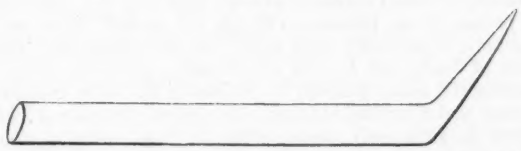
By a comparison with these figures an experimenter can judge of the fuel used.

The most accurate method for the ultimate analysis of organic substances is that adopted by chemists for the estimation of the carbon in coal.

The following apparatus is required, which I have placed upon the table:—

Combustion tube (Fig. 3) made of hard and annealed glass, in which

Fig. 3.

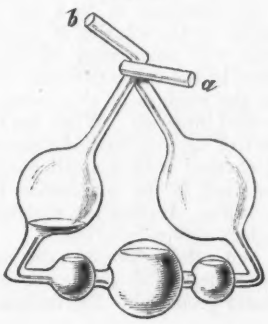


the coal is burned. Before using, it must be thoroughly cleaned and dried, by passing it rapidly over a flame, and sucking out the heated air by an inserted glass tube; when this is done it should be corked till required.

A small glass tube closed at one end to contain the coal, the cork of this should be covered with tinfoil.

Set of Liebig's potash bulbs, filled with a clear solution of potash, as free as possible from carbonate of potash, sp. gr. 1·27 up to $\frac{1}{3}$ of lower three bulbs, Fig. 4. Care should be taken when filling the

Fig. 4.



bulbs that only the end marked (*a*) should be inserted in the liquid; the bulbs are filled by applying suction to draw in the solution, the ends then perfectly dried with twisted bits of filter-paper and the outside with clean cloth.

A calcic chloride tube (Fig. 5), which must have a small portion of

FIG. 5.

cotton wool inserted before filling with calcic chloride.

When filled within three-quarters of an inch of top, another piece of wool should be inserted, and then closed with a perforated cork, through which a narrow glass tube passes; the protruding part of the cork cut off, and end covered with sealing-wax.

A furnace, in which the combustion tube is heated.

A quantity of fuzed chromate of lead, kept in a dry corked tube.

The process is as follows:—Weigh the potash bulbs and calcic chloride tube separately; then insert in the combustion tube some chromate of lead; add to this about half a gramme of dried coal, ascertaining the exact quantity by weighing the tube containing the coal, before and after the addition; then more chromate of lead, which must now be intimately mixed with the coal, using a clean wire, formed at the end like a corkscrew.

The contents of the tube are now placed so as to allow the gases to pass over the top, which can be done by gently tapping the tube on a table; then connect the calcic chloride tube by means of a dry perforated cork to the combustion tube, and the potash bulbs to the end of the calcic chloride tube with a vulcanised india-rubber tube. The potash bulbs should be carefully handled. The whole is now placed in the furnace, the bulbs resting on a piece of folded cloth. It is then requisite to test by slightly heating the bulbs, and allowing to remain a few minutes, whether the whole is air-tight. The furnace is then lit, and the number of gas-jets gradually extended until the whole is red hot. During this period the carbon of the coal will combine with the oxygen of the chromate of lead, and pass off as carbonic acid, but will be absorbed by the solution of potash; the hydrogen of the coal also combines with some more of the oxygen and forms water, which is absorbed by the calcic chloride. This operation should be performed so that the bubbles of CO_2 should only pass into the bulbs at about half second intervals. When the bubbling has entirely ceased, the pointed end of the combustion tube should be broken off with a pair of pliers; covered with a small glass tube about two feet long, and the CO_2 contained in the combustion tube sucked carefully through the potash solution. During the analytical process the bulbs must be kept in a slightly oblique position.

The potash bulbs, and calcic chloride tube, are now disconnected and re-weighed, the difference of weight in each case giving the amount of CO_2 and water produced. The calculation is now simple.

To find the carbon from the atomic weight of carbonic acid.

$$\begin{aligned} C &= 12 \\ O_2 &= 32 \\ \hline & 44 \end{aligned}$$

Then as 44 : weight of CO_2 : : 12 : weight of C, you can then, knowing the weight of carbon in a given weight of coal, calculate the percentage.

In a similar manner the hydrogen can be found.

H_2O, which is absorbed in the calcic chloride tube—

$$\begin{aligned} H_2 &= 2 \\ O &= 16 \\ \hline & 18 \end{aligned}$$

Then as 18 : weight of water : : 2 : weight of hydrogen, and, as before, knowing the amount of coal used, and hydrogen in that coal, the percentage also obtained.

Nitrogen is of such little moment that I will not take up your time in describing the tests for it, but proceed to an instrument, which I think should be in the hands of all persons who purchase large quantities of coal.

I allude to the calorimeter invented by Mr. Lewis Thompson. It consists simply of a glass cylinder, graduated to hold 29,010 grains of water, a combustion cylinder of brass, with stem and stop-cock, with spring clutch-base, copper furnace, and thermometer.

In using it, we assume the latent heat of steam to be 967° F., and that coal burned in oxygen gives off as much heat as when burned in air.

If we heat 967 parts of water 1° F., we expend as much heat as if one part of water were boiled off from 212° F.

Similarly, if heated 10° F., the heat would have been enough to have boiled off ten parts of water, the thermometer thus indicating the number of parts capable of being boiled off by the heat. If one grain of coal were burned in 967 grains of water, the temperature would show the number of grains of water the coal in question would convert into steam; by using tons, or pounds, instead of grains, we could thus find how many tons or pounds of water a ton or pound of coal would evaporate, thus giving an approximate value of its evaporative power.

In this instrument there are thirty grains burned, therefore the amount of water is increased thirty times, namely, to 29,010 grains. The coal used must be finely powdered, and passed through a hair sieve. Thirty grains of this powdered coal are then weighed in a perfectly dry state, and mixed with ten or twelve times its weight of a mixture composed of three parts of chlorate to one part of nitrate of potash; this is generally termed an oxygen mixture.

The coals must be reduced to powder separately, as the mixture is liable to ignite if pressure is used. Then intimately mix them and

place in a narrow copper furnace, tapping so as to fill it. The furnace is then placed in its position, and a hole made in the mixture to receive a fusee, which is fixed by pressing the mixture round it.

The temperature of the water is now taken by a delicate thermometer, and the fusee lit; cover with condenser, and quickly insert the whole under water, the stop-cock having been previously closed. This must be done smartly or it is dangerous, should it take fire in the air, perhaps burning the operator. It is generally found that if the water is about 60° F. before the experiment, the results are most reliable.

When combustion has ceased, the condenser is moved up and down to mix the water, and the stop-cock opened, from which air should issue; a thermometer is then quickly inserted, and from the temperature observed, the approximate evaporating value of the coal is calculated.

Each instrument itself absorbs a quantity of heat, which is ascertained by the making, and must be added to the result. The one before you absorbs 10 per cent. I will now, with your permission, perform this experiment.

There are other different kinds of calorimeters, one in which oxygen is carried into the combustion-chamber by a pipe, and the heated coal burned under water by these means; afterwards the calculations are then made in a similar manner to those used for Thompson's calorimeter.

Another form is a modification of that used by Rumford, Favre, and others, and as all these instruments have a kindred action, I will describe the one used at the Naval College.

A rectangular box of sheet iron made water-tight, 2 ft. × 2 ft. × 18 inches; within this is placed a small furnace about 5 inches square, in which fuel can be burned; to the top of the furnace is attached a copper tube, one inch in diameter, which coils round inside the calorimeter, and finally issues out at the top; through which the products of combustion pass. There is a fan in the interior which can be moved so as to mix the water intimately. The calorimeter must then be weighed, and filled with a known quantity of water. A pound of coal is burned in the furnace carefully; taking the temperature of the contained water at the commencement and end of the experiment. A similar calculation is then adopted as for Thompson's.

The weight of the calorimeter must be multiplied by the specific heat of iron, namely, 113, and the amount considered as so much more water raised in temperature.

Care must also be taken, that the gases only issue into the atmosphere slightly in excess of the temperature of the surrounding air.

A good practical method is adopted in our dockyards, in order to test the coal as it arrives. A tank is fitted which contains a known quantity of water; this is allowed to run into a boiler, and is there evaporated; known by having certain marks on the gauge glass. The coals used for this experiment are weighed as well as the ash made; and then its evaporative power can be calculated.

As these experiments are generally made in a special boiler, under

similar conditions, by the same person in each dockyard, I am sure they would make a valuable table of reference if published.

However, most of these testing apparatuses are too expensive for general use, but in the hands of ready manipulators, the Admiralty, or other large purchasers of coal, have in Thompson's calorimeter, a ready approximate method of testing the evaporative value of different kinds of coal. For practical men, the tests for water, ash, and the litharge-test for carbon, with the aid of the calorimeter, will, I am sure, be sufficient.

It often happens that an officer in Her Majesty's service, may have a piece of fuel given him in a far off land; with these tests he will certainly be able to form an approximate estimate of its value for the services, and by these means perhaps aid our ever-increasing steam fleet, which, as time rolls on, will require more and more coaling stations. If we can thus obtain supplies from other countries, we shall have more left for our home consumption, without which England must sink to the position of a second-rate power.

Devoid of coal we should be unable to compete with other nations in the production of those useful articles of commerce, which supply the very sinews of our maritime prosperity.

Mr. G. A. Tuck, R.N., Instructor in Steam, Royal Naval College, Greenwich: It would be a pity to let this subject pass over without some few remarks, especially as there are so many naval engineers present. However, a paper of this kind is for the benefit of sea-going men as a rule, therefore I should like to offer a few remarks as to what we may consider its value in a practical sense afloat in those foreign parts where we are accustomed and obliged to take coal as we can get it. I must say I do not feel at all able to question any point in this paper. I understand it to a certain extent, but it is to me a chemical paper on the subject of coal; it is an analysis of coal chemically illustrated. It also represents how much has been done in the Royal Naval College when we find such a paper as this written by one of the pupils of Dr. Debus and his assistants; it shows clearly, at any rate, that they have studied deeply a subject which is of vast importance to the naval engineer. But I am not so sure that if placed in the hands of a practical man, or a man dealing with the coal afloat, he would look upon it in any other light than as a satisfaction to see what can be done in the laboratory, and it will be also a satisfaction to know that all this that has been done in the laboratory is totally unable to be performed afloat. In the first place, in dealing with the coal, we have the calorimeter made up as a boiler, and in this calorimeter we get the power of the coal. Now I, of course in the Navy, have seen from time to time various scientific means used for burning this coal, that is to say, to make a more perfect combustion, in order to realise the value of the carbon in the coal. But what has been the result of all those introductions? After all we have found that we have been obliged to fall back upon the skilled labour of the men, that is to say, trained stokers are far better adapted to deal with this question, although they know nothing at all about the theory, than all the so-called scientific introductions that we have had from time to time for burning coal. I remember perfectly well a chief engineer being asked by an Admiral what he thought of all these introductions, meaning the arrangement for burning the so-called Baxter's mixture, and what effect it had principally in consuming smoke. "Yes," he says "smoke-consumers "without doubt, but steam destroyers," meaning by this that although they got rid of the smoke the combustion was so bad in another direction that coals were used without heating power, and without giving us the quantity of evaporation that they would under the ordinary conditions of the simple stoker dealing with the coal. It has been my fate in the course of my service to be called upon to report

on coal, especially when opening up Japan. I was sent out there in 1857 with an Officer from the Royal Engineers, in order to try the coal practically, in case all other methods should fail in getting any knowledge of the matter. All the tests that could be got at by the chemist were tried, especially the litharge test. This was an entire failure on all points, I suppose, because of the adulteration of the litharge, preventing anything like truth being come at as to any quality of the coal. That is to say, we would take the same quality of coal, try it under the same conditions, and find different results each time, although apparently it was the same coal. Chemical tests of course we had not. I believe Professor Thompson's machine has been introduced since that time, but I do not think that if I had all that is now known, and which has been so carefully placed before you, that that would have enlightened me or helped me one bit to have carried out the real comparisons that were drawn as to the value of the coals for the several classes of vessels that we had to deal with. This chemical test I should have put on one side altogether. It would have been a great gratification to me to have had this paper, because I should have known then the chemists could not have done anything at all, whereas under the conditions I was in, I did not exactly know what they could do. Therefore I consider this going into the hands of the engineers of the service will be a very great boon to them indeed. Men who have not had a chance of going through a course of chemistry will be glad to have this paper placed in their hands, and they will summarize the whole, and see how much can be done with coal. It is a difficult matter to discuss this paper, but I did not like to let it pass without some few remarks.

Mr. Thomas Wills, Demonstrator in Chemistry, Royal Naval College, Greenwich: With your permission I should like to make one or two remarks from a chemist's point of view, seeing that the subject, as it has been treated by Mr. Eckersley to-night, is essentially a chemical one. There can be no doubt whatever that any fresh knowledge regarding the materials which at any time may have to be used, will be of value; it will invariably lead to a more satisfactory use, economical and otherwise, of such materials. This is the direction in which the greatest advance has been made during modern times in our productive industries. Manufacturers have come to see that it is to their interest to know all they can about the raw material which they use; and in this way they are able to work upon a more or less scientific basis, and so to obtain the best results they can, and at the same time to prevent unnecessary loss. It is very much to be regretted that in the case of such a substance as coal, used in such immense quantities and for such diverse purposes, that at present there are no accurate and ready methods for its valuation, not only in this department, viz., in its application for the production of mechanical power in the steam engine, but also in its use as a means of obtaining warmth and heat, and also as a means for obtaining artificial light. In neither of these directions is there any ready and accurate means for determining the value of coal for that particular purpose for which it is required. There are methods, and they are theoretically accurate, and in some cases absolutely accurate, but they are not by any means ready; they are not quick in operation, not at all adapted for use in a commercial sense, and this seems to be the difficulty, that either accuracy must be given up, or celerity; we cannot have accuracy and quickness at the same time. The method Mr. Eckersley has introduced to you this evening, that of burning coal with chromate of lead, is a perfectly accurate method; it is the one which is adopted by chemists for the ultimate analysis of organic substances, by which they obtain an insight into the constitution of an organic body, and are able in that way to write down its formula, but although so accurate, that process is a very tedious one and requires several hours and a great amount of care for its completion, because it is the case that as you increase the accuracy of the result, you increase the amount of care which it is necessary to take in the manipulation; and a test of this description would be useless if it had to be applied in commercial operations. The litharge test of "Berthier," and the test with Thompson's calorimeter, may not be, and are not accurate, but they are made with very great care. It is quite possible the inaccuracy in these tests may not be greater than the inaccuracy in the combustion of the coal itself; for I believe it to be probable that in no two cases would a quantity of coal be found to burn alike, unless experimental conditions were resorted

to. So many matters come into play to influence and prevent the coal from giving out precisely the same amount of heat on two occasions; the arrangement of the furnace, the amount of air admitted, the heat of the furnace when the coal is put in, the thickness of the layer of coal, all these things and many others have to be absolutely alike before we can obtain two results that will be similar, because being such a complex substance it is capable of undergoing a variety of different decompositions, and under different circumstances will decompose into various products of different value. The combustion-test, with chromate of lead, is based upon the supposition that the whole of the carbon is burnt to carbonic acid. This is not the case when coal is burnt under a boiler, where the heat if it is to be of any value, must be evolved at a particular spot. The coal is burnt partly into carbonic oxide and partially into carbonic acid; the carbonic oxide is afterwards burnt into carbonic acid, but this takes place frequently only after it has passed away from the spot where the heat is required. The litharge-test is especially inaccurate when heavy stove-coals have to be examined, such as anthracite or South Wales coals, where the oxygen contained in the coal is very much less than the hydrogen. In one of the tables used by Mr. Eckersley, you have stated the carbon, hydrogen, and oxygen contained in wood, peat, and coal, and in the wood there is very nearly the theoretical quantity of oxygen to burn up all the hydrogen. Every one part of hydrogen would require eight parts of oxygen, so that it should be 96 of oxygen, instead of 83. Now, as long as the hydrogen and oxygen exist in the proportions in which they form water, none of the oxide of lead will be reduced to metallic lead by the hydrogen. But as you go down that table the amount of oxygen in proportion to hydrogen gets less; and, as it gets less, you have an excess of hydrogen which will reduce the oxide of lead. This excess of hydrogen is about four times as valuable in its heating-power as the carbon itself; and hence, in using the litharge-test, you would be estimating the calorific value of hydrogen as if it were carbon. This is one of the inaccuracies in the case of the litharge-test.

With Thompson's calorimeter there is always a proportion of heat goes off with the gases; the combustion is so energetic that the water cannot absorb the heat rapidly enough. But supposing the inaccuracies of these two methods not to be greater than the inaccuracies of the combustion of the coal, then they can be applied for estimating its value.

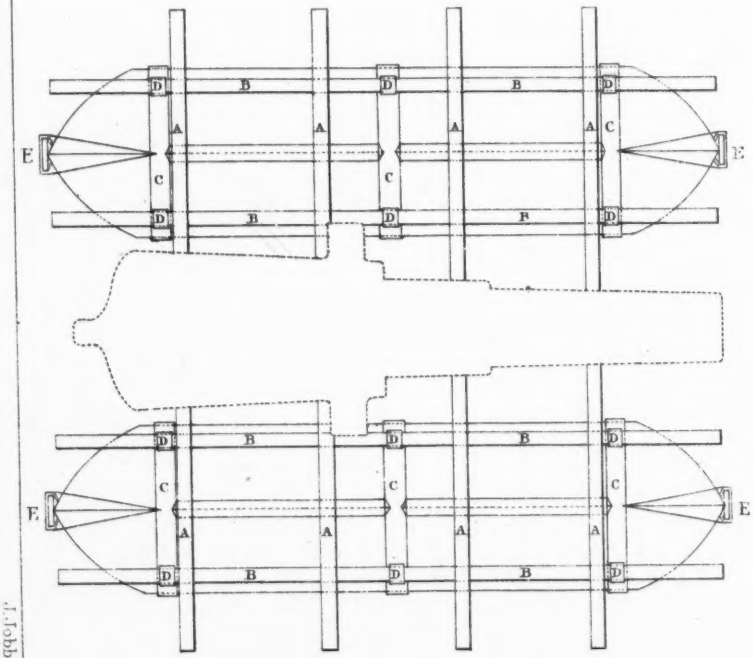
Again, I take it that coal is never required to be valued absolutely, it is nearly always a relative result which is wanted. You have two or more coals, and have to judge which is the best for your purpose. You are not asking the value of a particular coal, but relatively to another coal, how much carbon or sulphur does a certain sample contain. Taking even an inaccurate method, if the conditions are fulfilled in both cases, the inaccuracy will be the same in both cases, but the difference will be absolute and correct, so that you can form a very good estimate between the two coals. With regard to taking samples of coal, this is a very important point, because upon the sampling of the coal depends all the after-tests which we have had here mentioned. The coal must be sampled very carefully. A large quantity should be obtained, as much as one hundredweight at first, and the lumps which occur in greatest number and of a similar size, should be taken first, and a number of these should be put together and broken up into smaller pieces; these smaller pieces should be thoroughly mixed, and a certain number of these taken and again broken up, the residue mixed, and then pieces picked out again, and broken again, and mixed again, and so on until you have reduced the coal down to a fine, almost impalpable dust, and then this may be considered as a sample of the coal. Even when such precautions as these are taken, occupying a considerable time, it sometimes happens that a sample will not show the homogeneity it ought to do if it is to be considered as an absolute sample.

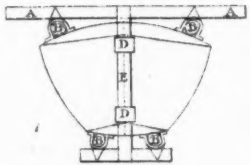
Captain BURGESS: I should like to ask what the apparatus on the table if supplied to a ship is likely to cost?

Mr. ECKERSLEY: About £5, I believe, is the value, and if the balance was made a little more sensitive, and the thermometer a little more sensitive, it would be beneficial for all the other tests.

The CHAIRMAN: Before asking you to thank Mr. Eckersley for his lecture, I should say I quite agree that in actual practice it is not so much the particular

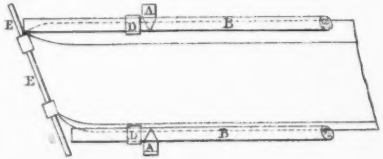
value of any sort of coal that is required, as its relative value compared with other coal that can be obtained in the market abroad. These experiments and all this accurate information are of very great use, even supposing we could not make them accurately on board ship; but I myself see no reason why we should not make these experiments on board our ships with considerable, if not perfect, accuracy. At any rate it is of great importance first of all to know what is in the coal, what quantity of heating materials we can get in a given fuel; then, having got that, to know how we can best apply the means at our disposal, that is to say, the furnaces in our ships to that peculiar fuel; and then comes in, what one of the gentlemen who favoured us with his opinions is quite right in saying, is the rough and ready and practical experience of the stokers how best to use that coal in the furnace which is at their disposal. We may find that by a little alteration of a furnace we may make a coal which is, comparatively speaking, unsuited to the furnace in its first form, well suited to it with a slight modification. That is decidedly the Engineer's Department on board of that ship. I think, not to occupy your time too long, that we have gained a great deal of information already from the lecture we have heard, and that all who go to sea will be able to turn that information to greater advantage now that we know more on the subject. You will all join with me, I am sure, in thanking Mr. Eckersley for his very able and interesting lecture. He is not only very well informed himself, but he has elicited information from others which we are all very glad to hear.





REFERENCES.

A . *Cross pieces connecting Pontoons.*
B . *Fore & aft poles rove through bands of canvas.*
C . *Bands of canvas round Pontoons.*
D . *Loops of Canvas on bands.*
E . *Stem piece.*



J. Tobbins

PROPOSED PLAN OF CANVAS PONTOONS TO BE MADE OUT OF SHIP'S STORES.

Contributed by Lieut. Arthur Moore, R.N.

These pontoons could be utilized as follows, viz. :—

1stly. Rafting bodies of men in shallow water, or through surfs.
2ndly. Transporting heavy weights in shallow water.
3rdly. Increasing the buoyancy of a raft.
4thly. As impromptu camels for raising sunken vessels.

To float a weight of approximately 6 tons, 2 portions of double No. 1 canvas, 12 feet long, should be made, and coated with the following solutions.

	Solutions.	*Mode of Application.*
For the seams.	1. Gutta-percha dissolved in naphtha.	To be rubbed between the parts of canvas before sewing.
	2. 6 lbs. of glue dissolved in boiling water, and mixed with 10 lbs. of whiting.	To be rubbed on the inside of the seams after sewing.
	3. 3 gallons of linseed oil, 1½ lbs. of rosin, ½ lb. of yellow soap, 1 lb. of litharge.	To be put on hot over all, working well into the seams.

And a final coat of black paint on the outer part.

Two cloths on top, one at bottom, and one on the sides, meeting at either end. The two parts should be cut out the same, but in sewing, the seams of the inner part should be broader than those of the outer. The ends to be rounded off at 18 inches, to avoid corners. The canvas to be sewn close on the inside with an inch seam, tabled and stuck on the outside, using a small needle with the edges smoothed. The hose to be on one side made of double canvas, one part first sewn on the inside, then turned inside out, and the other part sewn to the outside very close. The hose of the inner part coming up inside that of the outer.

The top to be sewn to the sides first, and the bottom going on last.

Application.

In all cases of transporting, rafting, &c., the pontoons must be connected together abreast with poles. To secure these, three or four

bands of canvas should be made to go taut round the pontoon when inflated fore and aft. Loops of canvas to be sewn on these bands, and also on the seams at either ends where the side cloths meet. Two poles to be rove at top and two at bottom, through these loops, and a flat piece of wood through the loops at the ends to make stern pieces that will protect the canvas from chafe, and to which the fore and aft bands of canvas should be secured, so that the pontoon, when in motion, would not chafe or slip out of the bands. Four short cross-pieces to be lashed underneath, and at right angles to the bottom poles, to keep the pontoon off the ground, and four cross-pieces to be lashed to the poles on top of each pontoon to connect the two together. The length of these last to be determined according to the distance the pontoons are required apart.

In transporting or rafting, a suitable platform should be made to rest on, and be secured to the cross-pieces connecting the pontoons.

In utilizing the pontoons as impromptu camels, the simplest plan would be to secure them when empty under the beams of a ship independently, and then inflate them. For this service they could be made of almost any size, and, if required in as short a time as possible, one part of canvas and two good coats of Stockholm tar might suffice.

For increasing the buoyancy of a raft they would be used in conjunction with the spars, which should be arranged so as to leave a clear space where the pontoons could be placed without danger of chafe. The bands and poles should be placed as before, the cross-pieces being securely lashed to adjacent spars of raft.

Experiment.

A partial experiment was tried at Trincomalee in November, 1873, and tested as follows:—

1. Placed empty under a 27 feet cutter, with 13 ten-inch shell, and 8 men in her. The boat was lifted easily.
2. Placed empty under the stern of an iron lighter 50 feet long, 15 feet beam, flat-bottomed. The stern was lifted 10 inches, leaving 4 inches of water under the lighter 10 feet from stern.
3. Two anchors, weighing together 62 cwt., were lowered on the pontoon, and purchases overhauled. The anchors sunk as far as the flukes, so actual weight sustained was about 50 cwt.

The results were satisfactory, considering the incomplete apparatus used, which consisted of a single pontoon ($11\frac{1}{2}$ feet long) instead of two, and that made of single canvas. The sole defect noticeable was in the seams, where an escape of air was apparent, but this would not be the case with double canvas. The canvas itself was perfectly air-tight.

The diver's air pump was used to fill the pontoon.

LECTURE.

March 12th, 1875.

Admiral Sir ALEXANDER MILNE, G.C.B., &c., &c., Lord of the Admiralty, in the Chair.

THE VOYAGE OF H.M.S. "CHALLENGER," (*continued*).

By Dr. CARPENTER, C.B., F.R.S., &c., &c.

MR. CHAIRMAN, LADIES, AND GENTLEMEN,

WHEN, about two years ago, you did me the honour to invite me to deliver a lecture on the voyage of the "Challenger," I was able to speak of little more than what was intended to be done: we had but one instalment, and that a small one, of what had been actually done; and my endeavour then was to explain to you the scientific objects of this very interesting expedition. I pointed out that these were essentially twofold, namely, *first*, the exploration of the Deep Sea as regards its Physical conditions, especially its depth, its temperature, and its composition, together with the study of the nature of the ocean-bottom, which has proved to be of peculiar interest and importance; and *secondly*, the search for the various forms of Life with which we believed that bottom would be found peopled even to its very greatest depths. I am now able to tell you a great deal of what has been done; and I shall chiefly dwell in this lecture upon the first part of the subject, because it is that with which, so far, we have been made most acquainted. By the kindness of the past and present Hydrographer to the Admiralty, I have been kept always supplied with the results of the observations forwarded from time to time by Captain Nares, as to the depths, temperatures, and specific gravities ascertained by his soundings; and these results are presented to you in these large diagrams, which contain most of the temperature—sections, at least of the Atlantic, prepared by the Officers of the "Challenger." The animal collections have been far larger than was at all anticipated. The Hydrographer to the Admiralty told me that when the "Challenger" went into Hong Kong, every jar and bottle in the ship was filled up with collections made since the ship left Sydney; and as I had been over the ship, and knew the enormous storage there was, I could form some idea of the magnitude of these

collections, which are now on their way home. Those forwarded from the Cape and from Sydney have already been received; but it has been thought preferable that these collections should remain in store till the return of the "Challenger," when Professor Wyville Thomson will arrange them, and distribute them to various scientific men according to what is suitable for the investigation of each. Still we know a good deal in general terms of the success of the second part of the enquiry which the expedition was charged to prosecute; a great number of new and very singular forms have been discovered; and, what is perhaps not less interesting, we know that a number of specimens have been obtained of types of which one or two only had been previously brought to light, and which, from their very anomalous character, had excited great interest amongst naturalists. Some of these have been examined by the naturalists of the "Challenger," and accounts of them have been published; but any description of them would be too technical for a lecture like the present. I shall confine myself, therefore, as regards what I have to say upon the animal life of the deep-sea bottom, to a point which has recently been brought into considerable prominence, the nature of the deposit at present going on upon the bottom of the Atlantic.

In the first place, I shall revert to the problem which it was one of the chief objects of the "Challenger" expedition to solve: the distribution of Temperature in the deep sea. This distribution is obviously the clue to those great movements of ocean-water, which are too slow to be detected by any ordinary mechanical means. I had been led by the researches which were commenced in 1868, and carried on through 1869 and 1870, to a general view of what may be termed a *vertical oceanic circulation* dependent upon difference of temperature alone; which appeared to me to be extremely important as accounting for certain facts in the distribution of the surface-temperature of the sea, and of terrestrial climate affected by it, which the ordinary ideas based on the Gulf Stream and other surface currents did not appear to me satisfactorily to explain. I have within the last few months learned that a doctrine entirely accordant with my own, and expressed in so nearly the same words that I might almost be thought to have myself adopted them, was promulgated in 1845, by a very eminent German physicist, Lenz, then professor at St. Petersburg, who had accompanied Kotzebue in his second circumnavigation voyage, 1825 to 1828. As this is one of the most curious examples of scientific anticipation with which I am acquainted, I would ask your attention to two or three facts I shall now state in respect to it.

When it was settled that Professor Lenz was to accompany Kotzebue on this voyage, he and his colleague, Professor Parrot, also a physicist of great eminence, tested the ordinary self-registering thermometers, for the purpose of determining the effect of pressure upon them. Having subjected these to hydrostatic pressure in a powerful press, they came to the conclusion that they were so much affected by that pressure, that they were valueless as indicators of the temperature at great depths. They then gave up the idea of using such thermometers, and

applied themselves to work out some other mode of obtaining deep-sea temperatures. The one which they devised certainly seems very bungling; and any seaman would at once say it would be exceedingly difficult to work satisfactorily, especially without the aid of the donkey engine with which all large steamers are now furnished. This method consisted in sending down a large wooden cask heavily weighted, with valves at the top and bottom; so that as, in its descent, the water would stream upwards through the valves, and these would close so soon as an upward movement was given to the cask, the water brought up in the cask would be that of the greatest depth to which it should have sunk. It was considered that a large bulk of water being thus brought up, and this being enclosed in a comparatively non-conducting case, it would retain its bottom-temperature almost unaltered; and the eminent French physicist, Biot, supplied Lenz with a formula for the correction which he should apply to the temperature actually observed when the water was brought to the surface through the warmer upper stratum, so as to make it indicate the temperature of the bottom water. Lenz published his observations in the Transactions of the St. Petersburg Academy in 1829; but they excited little notice; and he did not publish any general deductions from those observations until 1845, when D'Urville, the celebrated French circumnavigator, published his conclusion that the general temperature of the deep sea was 39°, alike in the equatorial and in the polar areas, a conclusion subsequently confirmed by the observations of Sir James Ross. Being convinced of the fallacy of D'Urville's observations and conclusions, Lenz published a short paper in the Proceedings of the St. Petersburg Academy, giving his general deductions from his own observations, and claiming that these were more trustworthy than the conclusions of D'Urville. That paper seems until recently to have escaped the notice of every writer who has subsequently taken up this subject. My eminent friend, M. Dumas, the Secretary of the Academy of Sciences in Paris, told me in the spring of last year that he did not know any one who had taken a view at all similar to mine, except Pouillet, with whose general opinion on the subject (never very definitely expressed) I was well acquainted. But in the summer of last year I learned from Professor Prestwich, of Oxford, that in searching out everthing that had been done on the subject of deep-sea temperatures, he had come upon this curious little paper of Lenz's, which I at once read with the greatest interest, finding almost in the very same words the general conclusions I had myself come to. The results obtained by Lenz's method, difficult and unsatisfactory as it seemed, really anticipated most remarkably, so far as they went, the temperature-observations taken by the "Challenger." But then Lenz's temperatures were almost entirely bottom-temperatures; with this exception, that he took temperatures with the ordinary thermometers down to about 400 fathoms. The conclusions at which Lenz arrived, and which were precisely the same as those I expressed in this room two years ago,[1] were these:—that owing to the greater density of polar water in consequence of

[1] See Journal, Vol. XVII, Page 528, *et seq.*

its low temperature (the fact that *sea* water continues to contract down to its freezing point at or below 27° being very well known to Lenz, although it had again escaped general attention,—I believe Sir James Ross and Sir John Herschel were both ignorant of it), a column of water of any given height will be much heavier when that water is at 29° or 30°, than a column of water we will say at 60°. If that be the case, it will also have greater lateral pressure; and the consequence will be that in any long vessel of water which is cooled at the surface at one end, and heated at the surface at the other, there will be a continual descent of water at the cold end, a continual flow of water along the bottom towards the warm end, a continual rising of water at the warm end, and a continual flow of the water which has become heated at the surface from the warm end towards the cold end again. I have exhibited this experiment at the Royal Institution more than once, by putting a box with freezing mixture on the surface of water at one end of a trough, and a heated plate at the other end; by that means I was able to keep up the circulation as long as the freezing mixture retained its low temperature. If you apply that to the case of the great ocean basin, you will at once see what we should expect as the result of this constantly-maintained opposition of temperature.

That was the view I presented in the former lecture; and I further developed this point,—that such a circulation would bring up cold water nearer the surface under the Equator, than it does anywhere in the Temperate zones. Now this fact had been actually discovered by Lenz, and had formed part of the basis of his doctrine. In ignorance of his discovery, I predicted that it would be the case; and I shall presently show you that the prediction has been verified by the "Challenger" soundings. Having found by the temperatures he took from the surface down to 400 fathoms, that there is a band of colder water underneath the Equator than there is on either side of it, and having also proved by his bottom-soundings the presence of polar water over the sea-bottom under the Equator, he affirmed that the only possible explanation of that band of cold water under the Equator is, that it is the polar water coming up from below. This is what Lenz had distinctly laid down in this paper of 1845; and all who were present here at my former lecture will recollect that that was precisely the expectation I stated of what the "Challenger" expedition would bring out.

Then I further pointed out, that owing to the difference in the freedom of communication between the two polar basins and the oceans in connection with them, there would be a much larger flow of Antarctic water into the Atlantic basin than of Arctic water, because the communications between the Arctic and the North Atlantic are, comparatively speaking, indirect and narrow. The channel between Iceland and Greenland, which, when looked at on a globe, not on a Mercator's chart, is seen to be really a narrow one, is the principal of these communications. The channel between Iceland and the Faroe Islands is blocked against the cold flow by a bank, which rises sufficiently near the surface to keep it back. Between the Faroe

Islands and the Shetland and Orkneys, there is that remarkable channel which I have ventured to christen the "Lightning" Channel, after the name of the surveying vessel assigned to us in 1868, in which the first observations were made that have eventuated in the "Challenger" expedition. The water to which this channel would give passage is a mere rivulet in comparison with the great basin of the Atlantic; and yet we found that through that channel was flowing a stream of ice-cold water below 30° of temperature, obviously passing towards the great basin of the Atlantic, and helping to keep down its temperature. Comparing the sum of all these with the complete, unrestricted communication between the Antarctic basin and the South Atlantic, I ventured to predict that we should find the South Atlantic altogether much colder than the North Atlantic; that the bottom-temperatures would be lower; that the cold water would flow over its bottom in a greater mass, and that very probably the Antarctic flow would pass northwards beyond the Equator, and show itself in lowering the bottom-temperature to the north of the Equator, instead of meeting the Arctic underflow beneath the Equator. I shall be able to show you that this prediction has been completely verified.

In the first place I may state, upon the authority of a very competent judge, that the working out of what may be called the "temperature-stratification" of the Atlantic alone, is the grandest single contribution that has ever been made to Terrestrial Physics. It gives us the temperature-stratification for about 15,000,000 square miles, carried down from the surface of the ocean to an average of 15,000 feet of depth: that is, a depth about the height of Mont Blanc.

Now I will briefly trace the course of this work. The first Section which I was able to exhibit to you on a former occasion in this theatre,[1] was taken from Teneriffe at 28½ to St. Thomas's at 18½. You observe the upper strata given in successive bands, each band representing 5° of temperature. This thicker line represents the isotherm of 40°; and all below 40° may fairly be considered as polar water, with some admixture of water of a higher temperature. The depth of this mass of polar water is very much greater than the depth of the warm water above; and in fact the strata from 65° to 70°, 60° to 65°, 55° to 60°, 50° to 55°, 45° to 50° are very thin. Indeed, we may assume that from 45° downwards, by far the greater mass of the Atlantic is water that has been more or less cooled down by the polar underflow. There is a very distinct proof of this, in which I find that D'Urville anticipated me. I have brought forward on more than one occasion the contrast between the temperature of the Atlantic and the temperature of the Mediterranean. Sir Alexander Milne will doubtless remember that when I had the pleasure of dining with him on board his ship in Gibraltar harbour, we were speaking of the deep-sea temperatures; and he told me, "I have been taking temperatures in the "Mediterranean, and I find that after the first 100 fathoms the tempe-"rature is uniform." Going into the thing very systematically and carefully that summer, I found it precisely as Admiral Milne had stated. The surface-temperature went up to 70°, 75°, and 80° between

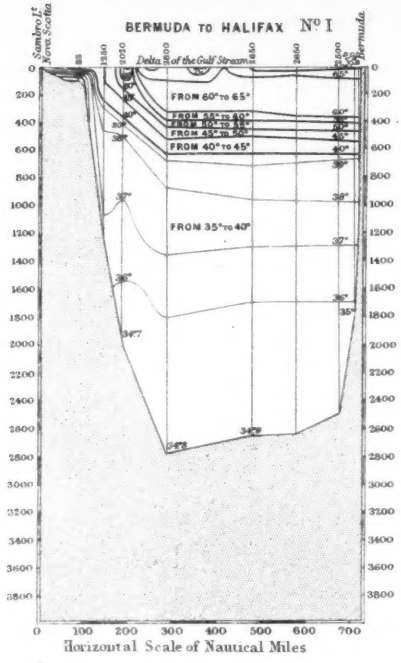
[1] Plate XLV, Vol. XVII.

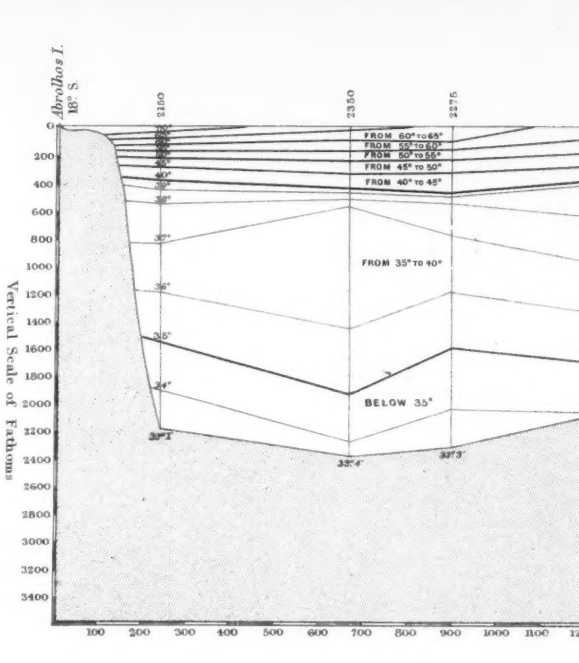
Malta and Tunis: but the greater part of that super-heating was lost in 50 fathoms; and from 100 fathoms down to the bottom depth of 2,000 fathoms the temperature was uniform at 54°, 55°, or 56,° according to the locality. What is the reason of this? It is because the Mediterranean is shut in from the Atlantic. The ridge at the western end of the Strait of Gibraltar is comparatively shallow; its depth is nowhere more than 200 fathoms, and a great part is less than 100; so that no cold water can find its way into the Mediterranean. Hence the uniform temperature of the Mediterranean is what we now call the *isocheimal*, the mean winter temperature of the locality: that is, in winter it is uniform from top to bottom, 54°, 55°, or 56°, as the case may be; whilst, on the other hand, in the summer the surface-stratum becomes superheated under the influence of the direct solar power. The uniform temperature of the basin itself is determined solely and entirely by its geographical position. You will see, therefore, that there must be some extraneous influence to cool down the whole of that mass of water under the same parallel of latitude in the Atlantic basin outside, as compared with the water of 55° inside the Mediterranean; and I find that D'Urville had given precisely the true explanation, that no polar water can find its way into the Mediterranean. We shall presently see that there are some very curious cases of the same kind, which have lately been worked out by the "Challenger."

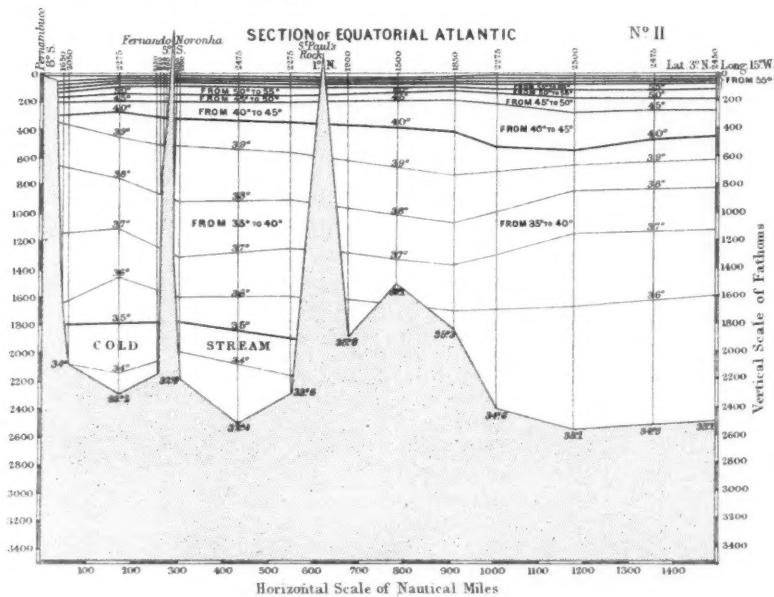
Again, whilst the bottom-temperature of the North Atlantic is shown in this Section to be generally 35½°,—which corresponded with my anticipations derived from my own soundings, and with what I could judge to be the corrected temperatures obtained by Captain Chimmo and others, you observe that as we get nearer the Equator the temperature of the bottom falls, so that it is 34·8 near St. Thomas's. Now, when I first saw this section, I had a very strong suspicion that this depression marked the extension of the Antarctic underflow to that point; and I shall presently show you that this is clearly the case. We have here evidence of the presence of Antarctic water, north of the Equator, in the depression of the bottom-temperature to a point below that found over any part of the North Atlantic basin, properly so called.

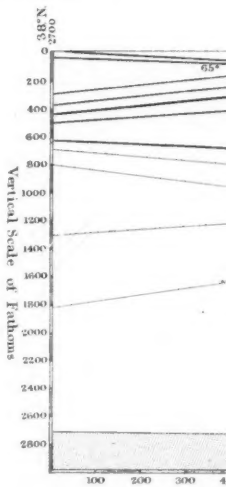
I beg you to notice the general depth of the upper stratum above 40° in this first section, and also in the section which was taken on the return-voyage between Bermuda and the Azores. (*See* Plate XLIIa, Sect. IV, 38° N.) You will remark a difference in the stratification in this, that the band between 60° and 65°, is remarkably thick in the western portion of the latter, thinning off towards the Azores; and I am not very clear what the explanation of that excess of thickness is.

There are one or two very interesting points in this second section, to which I would expressly direct your attention. The "Challenger" after leaving St. Thomas's went straight north to Bermuda; and one of the soundings taken near St. Thomas's was remarkable for its extraordinary depth, which was the greatest that had been ascertained up to that time. (You may have seen some statements in the newspapers


BERMUDA TO HALIFAX Nº I
Sambro Lt
Nova Scotia
Bermuda
Delta of the Gulf Stream
FROM 60° TO 65°
FROM 55° TO 60°
FROM 50° TO 55°
FROM 45° TO 50°
FROM 40° TO 45°
FROM 35° TO 40°
Horizontal Scale of Nautical Miles

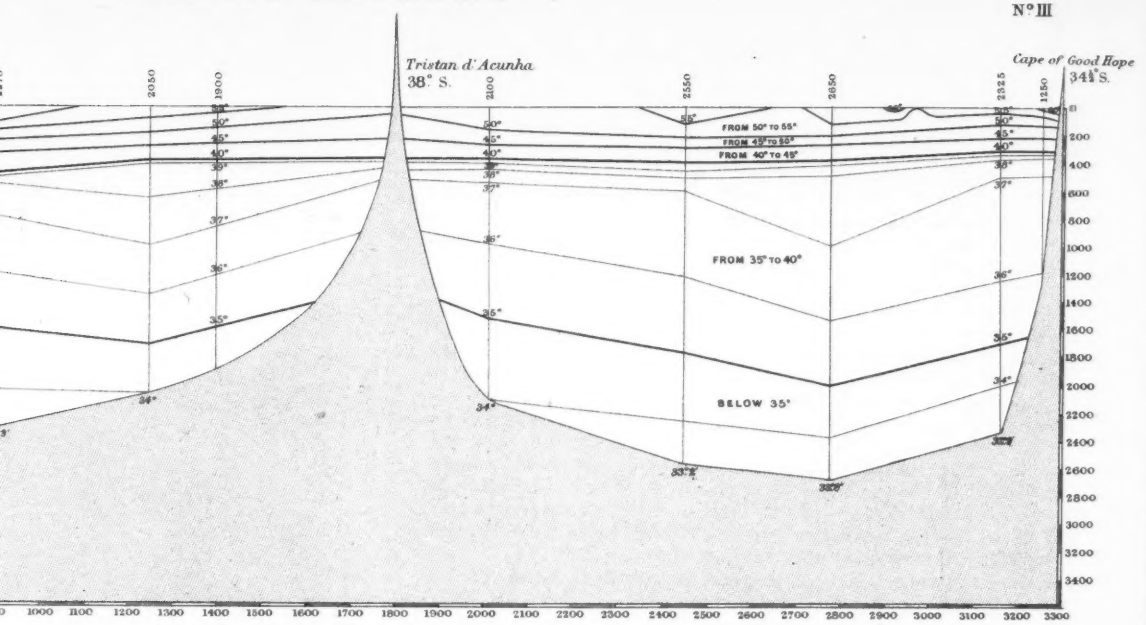

Abrolhos I.
18° S.
FROM 60° TO 65°
FROM 55° TO 60°
FROM 50° TO 55°
FROM 45° TO 50°
FROM 40° TO 45°
FROM 35° TO 40°
BELOW 35°
Vertical Scale of Fathoms


SECTION OF EQUATORIAL ATLANTIC Nº II
Pernambuco
8° S.
Fernando Noronha
St Pauls Rock
Lat 3° N. Long 15° W.
FROM 55° TO 78° AT SURFACE
FROM 50° TO 55°
FROM 45° TO 50°
FROM 40° TO 45°
FROM 35° TO 40°
COLD
STREAM
Vertical Scale of Fathoms
Horizontal Scale of Nautical Miles


38° N.
Vertical Scale of Fathoms

SECTION OF SOUTH ATLANTIC

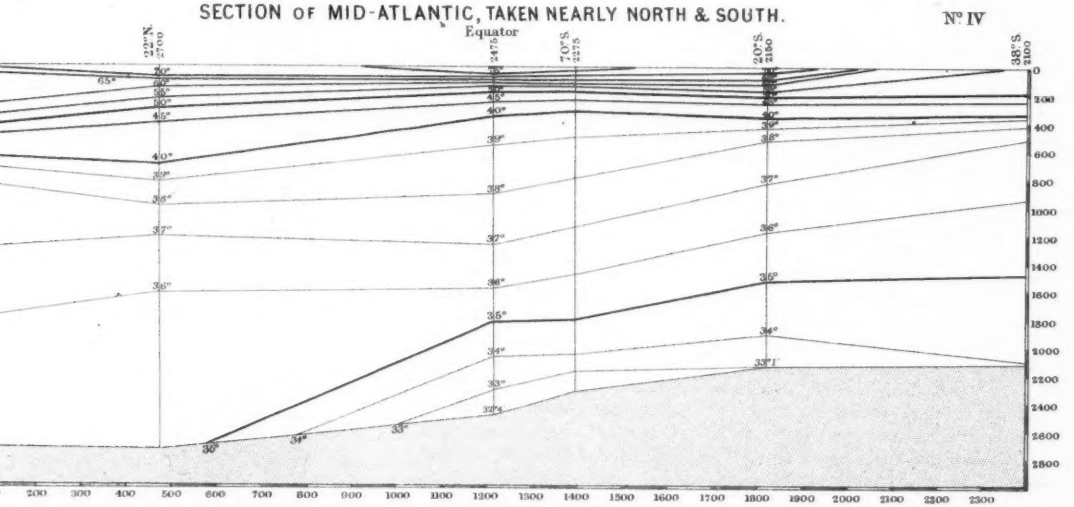
N° III



Horizontal Scale of Nautical Miles

SECTION OF MID-ATLANTIC, TAKEN NEARLY NORTH & SOUTH.

N° IV



Horizontal Scale of Nautical Miles

of extraordinarily deep soundings taken by one of the American exploring vessels near Japan. I must say I utterly mistrust those soundings, for I cannot believe the depths can be as great as they are represented—6,000 or 7,000 fathoms;[1] and certainly the inference drawn, that that enormous depression was scooped out by the surface current, is perfectly ridiculous and absurd.) This curious depression seems to be a sort of volcanic hole. Captain Nares was very confident about the truth of this sounding, 3,875 fathoms, though it showed a depth nearly a thousand fathoms greater than that of any part of the Atlantic previously sounded. It was a good up and down sounding; all the circumstances were favourable, and they could very well tell when the sounding apparatus reached the bottom. Further, there was a very curious fact which proved that that sounding was really a much deeper one than any that had been taken in making the previous section; namely, that the thermometers, protected according to the method I described to you in my former lecture, were both of them crushed by the tremendous pressure. They had been subjected over and over again to a pressure of $3\frac{1}{2}$ tons on the square inch, but they could not stand a pressure of nearly $4\frac{3}{4}$ tons.

The soundings taken in the neighbourhood of Bermuda verified the idea that this group of coral islands is really the summit of a very tall column of coral, not the top of a submarine mountain; for the proportion of its base to its height seems far too small for any mountain with which we are acquainted, being quite different from that of the Matterhorn for example. The slope was found to be so steep outside the Bermuda platform, that dredging could not be carried on upon it. I must not go into the theory of this; but taking Mr. Darwin's view of the structure of the coral islands, I should judge that this column, the base of which probably rests on a submarine mountain, must have been built up during a progressive subsidence of the bottom; the coral animals growing sufficiently fast at the summit to keep the living stratum near the surface, while the bottom was gradually sinking, for if they were once depressed 120 feet below the surface they would have ceased to live.[2]

The "Challenger" then went north to Nova Scotia and New York, and in this section (Plate XLIIa, No. I)[3] is a point to which I wish specially to direct your attention. You all know that there is an Arctic current coming down between the Gulf Stream and the coast of America; and that the transition between this current and the inner side of the Gulf Stream is very abrupt, constituting what our American friends call the "cold wall," though the Gulf Stream on its outer side graduates almost imperceptibly into the general surface-stratum of the Atlantic. On an occasion on which this cold wall was crossed by our Chairman, a thermometer, hanging from the bow of his ship in the Arctic current showed 43°, while a thermometer hanging from

[1] The greatest depth really determined by the "Tuscarora" was 4,655 fathoms.

[2] The "Tuscarora" soundings in the North Pacific indicate that a much more rapid depression, submerging several coral islands, has taken place in that area.

[3] The Institution is indebted to the Council of the Royal Geographical Society for the use of the Plates where the illustrations to this lecture were taken.—ED.

the stern in the Gulf Stream showed 66°, the difference of 23° within the ship's length, shewing the great abruptness of this transition. This low temperature represented not the ordinary temperature of the Atlantic, but that of the special Arctic current, which brings down the icebergs in the early summer that are the terror of our navigators going at high speed through those seas, and which also produces fogs where it meets the warm vapour-laden atmosphere above the Gulf Stream. Now this Arctic current is undoubtedly in its beginning a wind-current; for strong northerly winds prevail during a considerable period of the year along the coast of Labrador. But it is something else besides. This cold band cannot be traced as a distinct current further south than New York; but still it is followed southwards by the United States coast-surveyors as far as the Florida Channel itself; and they have even traced it by its low temperature beneath into the channel of the outflowing Gulf Stream, and have no doubt whatever that this cold surface-flow passes in beneath the Florida current into the Gulf of Mexico.

Now, if this "cold band" cannot be traced southwards as a current, the question naturally arises how does it come to be there? I had suggested the explanation to be, that this band, intervening between the coast-line of the United States and the Gulf Stream, is really the surging up of the cold underflow that is passing from the Pole towards the Equator. I may presume that all of you will see that it follows from the general principle of inertia, that while the rotation of the earth will carry round with it any *stationary* water at its own rate, yet that when water is moving from the Equator to the Pole, or from the Pole to the Equator, as the rate of the movement in the actual situation differs from the rate the water has brought with it, there must be a change in the relative position of the water and its basin, if it is free to change. Thus you will recognise this general fact, that a stream of water moving from the Equator towards the Pole, and carrying with it to a certain degree the rapid rotary motion of the earth, will have an *excess* of easterly momentum tending to carry it eastwards, as we see in the case of the Gulf Stream. So any flow from the Pole towards the Equator will bring with it a *deficiency*, of easterly momentum, that is, it will have a westerly tendency; and thus, if there be really the continual underflow of polar water I have argued for, that cold underflow will tend to the west, so that, as I surmised, it would flow up the Atlantic slope and very likely come to the surface. This is precisely what the "Challenger" soundings have shewn it does. You must understand that all these slopes appear about 100 times more steep than they really are, because in sections of this kind it is necessary to exaggerate enormously the vertical in proportion to the horizontal measure. Observe that at only 83 fathoms depth, off Nova Scotia, they actually came down to a temperature of 35°, the lowest bottom-temperature of the extra-tropical portion of the North Atlantic, and that the less cold strata overlying this came to the surface in the immediate neighbourhood. There, again, is the section of the Gulf Stream, and you see what an extremely small rivulet it is (so to speak) in comparison with the

great Atlantic. Last year I had the good fortune to meet Captain St. John, who has been surveying the Japan seas, and he told me that between the Kuro Siwo, the Gulf Stream of the Pacific, which follows the eastern shore of Japan towards Behring's Straits and Japan, there is a cold band of exactly the same kind. And I have another quite as curious confirmation of this view nearer home. Speaking of it to my friend, Dr. Meyer, of Kiel, who has been devoting much attention to the study of the physical conditions of the Baltic Sounds, and taking observations of the movement and temperatures of the water, he says, "I will tell you exactly the same thing in the North Sea." You know that the North Sea is shallow, *i.e.*, what we now call shallow as compared with the enormous Oceanic depths, being nowhere beyond 100 fathoms except near the coast of Norway, where there is a deeper channel. Now, along that deeper channel there flows southwards a cold stream obviously of Arctic water, which has been traced as far as the Cattegat. If that is flowing southwards, you will see at once that it will have a westerly tendency; for, bringing with it a deficiency of easterly momentum, it will tend to flow up the western slope of that channel and over the floor of the North Sea. That is what it does; it flows up the side of the Dogger Bank; where within five fathoms of depth there is a difference of 15° of temperature. Mentioning this to my friend Mr. Gwyn Jeffreys, who had dredged on the Dogger Bank, he said, "Then that is the explanation of my having dredged Arctic shells on the Dogger Bank."

The point I next have to advert to is the extraordinary confirmation of the view I presented to you, which is afforded by the next section. Here (Plate, No. II) is the Equatorial section taken between 3° north and 8° south. Compare the thinness of the stratum above 40° with the thickness of the same stratum in Section I, and you will see the marked contrast; water of 40° coming up in the neighbourhood of the Equator actually within 300 fathoms of the surface, whereas to the north of the tropic it lay at a depth of more than 600 fathoms. The cold water thus came up under the Equator nearer the surface than it had done anywhere else in the whole previous survey of the "Challenger." Notice, again, that the bottom-temperature falls almost to 32°, and that there is a thick stratum of water below 35°, the whole of which must clearly be Antarctic water. In crossing the South Atlantic (No. III), you still see this upper zone above 40° to be very much thinner than in the North Atlantic in corresponding latitudes; though not so thin as under the Equator, its general thickness being about 600 fathoms. This South Atlantic section shows that its basin contains a vast mass of water below 35°: and there must be some part of it where the bottom-temperature falls to nearly 32°, to bring such water into the equatorial zone. This would probably be on the western side; but from unfavourable weather the soundings were taken at long intervals; and very likely they missed some deeper channel bringing water at 32°, or very little above that temperature.[1]

[1] This has been proved to be the case by the soundings taken along the western side of the South Atlantic in the return voyage of the "Challenger."

You see that these facts all correspond precisely with the anticipations I ventured to form; and I have brought them into distinct view in Section IV, projecting a certain series of soundings, so far as to follow a north and south course between 38° N. lat. and 38° S. lat. Here you see the upper layer generally diminishing in thickness, coming under the Equator to its extreme of thinness and then gradually thickening again, whilst the surface temperature diminished; while at the bottom you observe the Antarctic flow of water below 35°, which shews itself northwards as far as St. Thomas's. This section also brings into distinct comparison the excess of thickness of the warm upper stratum of the North Atlantic, as compared with the corresponding stratum in the South Atlantic. This I am disposed to connect with the relative forms of the two oceans; for while the North Atlantic contracts in breadth as we follow it northwards, so that its poleward-moving upper stratum will be compressed laterally, and therefore thickened vertically, the South Atlantic widens out as we follow it southwards, so that *its* poleward-moving upper stratum will tend to spread out laterally, and therefore to thin away.

Now there is a most remarkable confirmation of this view of the uprising of the polar water, in this circumstance,—that according to the observations made in the "Challenger," which fully confirm those previously made by Humboldt, Lenz, and various other observers, whilst the *salinity* of the surface-water increases as far as the Tropic, say from 38° north, it was found to diminish towards the Equator, and then to increase again in passing to the south. In a lecture I gave three years ago at the Royal Institution, I ventured to surmise that this reduction of salinity in the equatorial zone is due to the up-rising of the polar water from below; and in this, too, I now find myself to have been anticipated by Lenz. Observe what takes place here. Polar water is heavier because it is so much colder; but it is less saline. The colder water may be traced the whole way along the sea-bed, from the Pole to the Equator, not only by its reduced temperature, but by the lower specific gravity, it shows when compared at the same temperature with the surface water of the temperate region. If polar water be coming up from the bottom, under the Equator, the salinity of equatorial water will thus be reduced: and that is precisely what was found by the observations of the "Challenger." I think that, putting those things together, you cannot hesitate in the belief that there must be a continual uprising of Polar water as represented in this diagram.

Then there is another thing,—the depression of the surface-temperature of equatorial water,—a point of very great importance, both scientifically and practically. I was not myself at all prepared for the evidence which this affords, until I came to acquaint myself with the temperatures reached in the Red Sea. The Red Sea does not receive so strong an insolation as Equatorial water, because, of course, under the Equator, the sun shines almost vertically the whole year round. Yet we find that in the Atlantic, under the Equator, the water very rarely rises above 80°; excepting under the influence of land, along the Guinea Coast, for instance, where the bottom is shallower, so that

there is no polar water to come up to the surface, and where the surface-temperature rises to 85° and 87°. But in the Red Sea, the temperature rises very much above this; and collecting the observations made upon the subject in the voyages of the Peninsular and Oriental steamers, we find that during August and September it is very common for the temperature of the Red Sea to rise to 96°, 98°, 100°. and in one voyage it was found, on three consecutive days, to range from 98° to 104°. Nothing of this kind was ever known under the Equator in the open Atlantic; and why? Because, as I believe, the equatorial surface-temperature is moderated by this continual uprising of polar water from the bottom.

Look again at the geographical position of the Mediterranean, which lies for the most part between 34° and 40° N. lat., as compared with the equatorial Atlantic. In the Mediterranean, during the summer months, I have myself seen the surface-temperature range for two months between 75° and 80°; and that is just about the annual range of the surface-temperature underneath the Equator. You see, therefore, what an extraordinary moderating influence this uprising of polar water has upon what would otherwise be the unbearable heat of Equatorial regions.

I would just return to the interesting fact that the "Challenger" has met with several cases of what was pointed out some years since by Captain Chimmo, in his survey of the Sulu Sea which lies between the northern extremity of Borneo and the Philippine Islands. Though this is not apparently a circumscribed sea on the chart, it is really circumscribed; for there are reefs which rise nearly to the surface, and a line of small islands, altogether enclosing a deep depression. Captain Chimmo found that the temperature of this sea closely corresponds down to a certain level with the temperature of the China Sea outside, presenting almost precisely the same stratification: but that from this level downwards, the temperature is uniform, continuing so to the bottom. That clearly shows, as Captain Chimmo said, that there is a polar underflow, which is prevented from acting on that deeper portion of this sea which is shut in by these encircling reefs. The "Challenger" has met with cases of the same kind; and this conclusion has been arrived at; the temperature stratification outside being known, the depth to which the communication extends may be judged of by what is the constant temperature down to the bottom; because, supposing this communication to stop at any given plane, the temperature of the water at that plane would be the constant temperature of all the waters beneath it.

Now let me say a few words upon the deposit in process of formation upon the bottom of the Atlantic Ocean. We were able in our "Porcupine" expeditions to confirm all that had been previously stated with regard to the enormous extent of the white mud composed of the calcareous remains of those curious little animals, the *globigerinæ*, which are excessively minute shells formed by animals of the utmost simplicity—little jelly-specks—the size of these shells being so minute that hundreds of them would only weigh a grain. It has been found, by microscopic examination of Atlantic soundings many years

before, that over a very large part of the bed of the Atlantic there is a deposit of unknown thickness, composed either of the shells themselves, or of their disintegrated remains. We ourselves brought up, in one instance, near the Faroe Islands, as much as half a ton of this white mud, composed almost entirely of the remains of these globigerinæ. In the first very deep dredging, 2,435 fathoms, off Ushant, in 1869, 1½ cwt. of this Atlantic mud was brought up, with a considerable number of living animals. We then came to the conclusion that these animals are living on the bottom. I never myself denied that they might be found floating on the surface also; but I was very strongly of opinion that they were alive on the bottom; and we know that they afford food to other marine animals of the same locality. In fact, I have been accustomed to say, we ourselves feed upon them indirectly; for we send our fishing vessels to the Faroe and Iceland banks to fish for cod; the cod feed upon a particular kind of star-fish that abounds there; and, upon examining the star-fish, we found their stomachs loaded in the same manner with globigerinæ; so that we may trace some of the protoplasmic material of our bodies back to the globigerinæ. One of the remarkable observations made in the "Challenger" has been, that the floating of these animals is very much more frequent and general than was previously supposed. By carefully searching, not only the surface-stratum, but the 100 fathoms stratum, with nets hung from the ship, they caught these animals in large numbers and in very curious conditions; for those that they found floating from the surface had the most delicate possible calcareous spicules radiating from them. Professor Wyville Thomson has entirely changed his previous opinion, that these animals live at the bottom, and concludes now that they do not live at the bottom at all, but only drop there after death. I am still unable to adopt this conclusion; because, having made a special study of these shells twenty years ago, I found the shells of the animals lying on the bottom to be very much thicker than those of the young animals found floating. I could not believe that the former *could* float. If the calcareous shell comes to be so thick that its excess of weight above the sea water is greater than the buoyancy of its contents, of course it must sink; and I am still inclined to the belief that they both live and breed at the bottom: for I have obtained water at the depth of 700 fathoms which was white with minute globigerinæ, floating just above the mass of globigerinæ mud that covered the bottom. I have been lately re-examining my old sections; and I see, as Dr. Wallich had also seen, that the shell is so thick that we cannot believe it could have floated after having acquired that thickness. Hence I am disposed to believe that the *globigerinæ* breed at the bottom, that the young rise to the surface and live near it during the whole time that their shells are increasing in the number of their chambers. There are generally about sixteen chambers in the adult: and when the whole of the chambers have been formed, and formed as very thin shell, then the calcareous matter which would go on forming new chambers is not so used, because the chambers are not further multiplied; and my belief is, that then the calcareous matter is deposited upon the surface, in-

creasing the thickness of the shells; and that when the shell has attained a certain thickness, the animals sink to the bottom, still continuing to live there, as other Foraminifera can be certainly shown to do.

Now I come to another very interesting question, namely, that of the origin of a very remarkable deposit of red clay, which has been found by the "Challenger" over considerable parts of the area of the Atlantic, having been especially noticed in the section between Teneriffe and St. Thomas's. They first came upon it in the deepest part of the eastern basin; and then after passing the "Dolphin Rise" they came upon it again. Professor W. Thomson at first very naturally surmised that this red clay is the product of some great river discharging its contents into the Atlantic; but he failed to be able to trace it to any such source, and did not find it in any but very deep water, where it seemed to take the place of the *globigerina ooze*. Hence he has been led to the conclusion that it is in some way or other derived from the globigerina deposit itself; and has offered this surmise—that it is (as it were) the ash left by the shells of the globigerinæ, when their carbonate of lime has been dissolved by an excess of carbonic acid in the very deep water. He thinks that, as this excess increases with the depth, the very deep water will dissolve the calcareous shells of the globigerinæ, leaving an insoluble residue, this combination of silex with alumina and iron. The only evidence he gives of it is, that he took some of what is called the globigerina ooze—not that formed of living shells, but the result of their disintegration—and that, on analysis of this, he found a small residue of red clay, amounting to about one per cent. My surmise (for I do not offer it as more) is of a different kind, and is connected with another very curious fact, encountered on a large scale in the "Challenger" expedition. It was many years ago observed by Professor Ehrenberg, that on examining the grains of green and ochreous sand, occurring at various geological periods, also composed of silicate of alumina and iron, he was able to recognize in them most distinctly the forms of the internal cavities of Foraminiferal shells, these grains being the internal casts of various kinds of *foraminifera*. Soon afterwards, the soundings obtained by the United States Coast Survey in the Gulf of Mexico having been microscopically examined by the late Prof. Bailey, of West Point, he found in them representatives of living foraminifera, whose cavities were similarly filled, showing that the like process is taking place at the present time. This set going a like enquiry on the part of those who had been paying attention to the subject on this side of the water; and having put into dilute acid some specimens obtained by Mr. Jukes in his dredgings on the coast of Australia, we got out the most perfectly beautiful internal casts—models of the animals which formed the shells—by dissolving away the shells with dilute acid. Three or four years ago, I came into possession of some dredgings which Captain (now Admiral) Spratt had made in the Ægean some years previously; and in the foraminifera of these Ægean dredgings I found the same thing—the most perfect green and ochreous internal casts of living Foraminifera.

Again, I find in the "Challenger" reports, that on the Agulhas Bank there was brought up a quantity of green mud, which on examination with the microscope was found to be entirely composed of these internal casts, the shell having been got rid of, possibly by friction, which is not at all unlikely in a current. This green mud, then, is the result in the first place of the deposition of a ferruginous silicate in the place of the animal. How this deposition occurs is a curious chemical question, which I brought under the attention of the Chemical Section of the British Association, last autumn, at Belfast. It is one of singular interest; and there was no hesitation among the eminent chemists present in endorsing my view that this deposition is the result of chemical *substitution*,—the deposit of silicates taking the place of the animal matter. It seems impossible to account for it in any other way. Why it should occur in some localities and not in others, we are not at present able to explain; possibly there may be differences in the composition of the sea-water covering different parts of the sea-bottom. But here is the fact that the ferruginous silicates are drawn into the cavity of the shell, and are deposited from the solution as solid mineral bodies, during the decay of the animal substance which previously occupied those cavities. Now my suggestion is that this red mud is simply a chemically metamorphosed form of this internal deposit; and we have this further evidence of it, that amongst Captain Spratt's specimens I find several of the internal casts which are formed, not of a green or ochreous silicate, but of a *red* material; and one in which the green graduates into the red, clearly showing that there is some chemical agency which tends to convert the green mineral into a red mineral, probably by a change in the oxidation of the iron. Hence I do not think it is at all difficult to understand that further change should produce a disintegration of this mineral; for we find in some of these casts the green mineral clearly efflorescing into a yellow powder. That is the explanation which I venture to offer; it is on its trial at present. A good deal of discussion will no doubt take place as to the whole subject. I shall have a number of the larger foraminifera carefully analysed; and if I find that these shells do not yield any ash from which this red mud can be derived, I shall have a right to say that the globigerina shells do not contain it. If I find that it does yield a red residuum, then I shall be perfectly willing to accept my friend Professor Wyville Thomson's view, that this red ash is the result of the solution of the calcareous part of the globigerina shell. I am very strongly inclined to agree with him that in any case this red mud is probably a derivative of this remarkable globigerina deposit, taking its place where we do not find the globigerina ooze: and in that point of view it is a fact of singular geological interest which I must not now detain you to dwell upon. You will find a very interesting lecture on it by Professor Huxley in the last number of the *Contemporary Review*, to which I refer you for a masterly summary of the facts at present known in regard to the agency of minute forms of animal and vegetable life in producing both calcareous and siliceous deposits on the sea-bottom.

The CHAIRMAN: We all feel deeply indebted to Dr. Carpenter for the kind

manner in which he has come to this Institution, and given us such valuable information with regard to the interesting soundings taken by the "Challenger." There is no doubt that the theories which have been established of the great depths of the ocean and of the polar current have been clearly portrayed by Dr. Carpenter in the diagrams which he has put before us; and it is certainly a matter of great interest to trace the curious theory which has now been established of the polar current rising from great depths to near the surface in lat. 22, and even to the north of the Equator. Dr. Carpenter alluded to the Gulf Stream, and happened to mention my name. With regard to that remark, it was a simple observation going from Bermuda to Halifax, when we were passing from the Gulf Stream into the apparently colder water on the banks of Nova Scotia. We saw smooth water a-head and a well-marked line of tide, and having always taken the temperatures from Bermuda to Haxifax, the small bucket was put over as the ship's bow was approaching the line of demarcation, and the temperature was 66° or 67°; and the moment we got over this current line into smooth water, the temperature was 43°. I was very much struck with it at the time, and attributed it to the fact that it was the Gulf Stream impinging upon the banks of Nova Scotia, and bringing up the cold water from below that had come from the polar regions. Dr. Carpenter also alluded to the temperature in the Mediterranean when my flag-ship was lying inside the Mole at Gibraltar. I found the temperature of the surface water was 70°, but at the keel of the ship it was 59°. This seemed to me to be caused by the great rush of the current at the entrance of the Mediterranean bringing up the cold water from below. I found it so useful there that we kept the ship alongside the Mole several days in order to get the ship cooled down. I found the same reduction of temperature in the Straits of Messina, the strong current brought to the surface the cold water from below, reducing the temperature at the anchorage to 60° and 61°; and I felt at that time that the temperature was the most cool and agreeable that we had experienced in the Mediterranean.

I am sure I may convey the thanks of this meeting to Dr. Carpenter for the very interesting and instructive lecture he has so kindly delivered to us.

Friday, July 2nd, 1875.

ADMIRAL SIR HENRY J. CODRINGTON, K.C.B., in the Chair.

EXPLANATION OF A JURY-RUDDER.

By Captain Sir J. E. COMMERELL, V.C., K.C.B., &c., the Inventor.

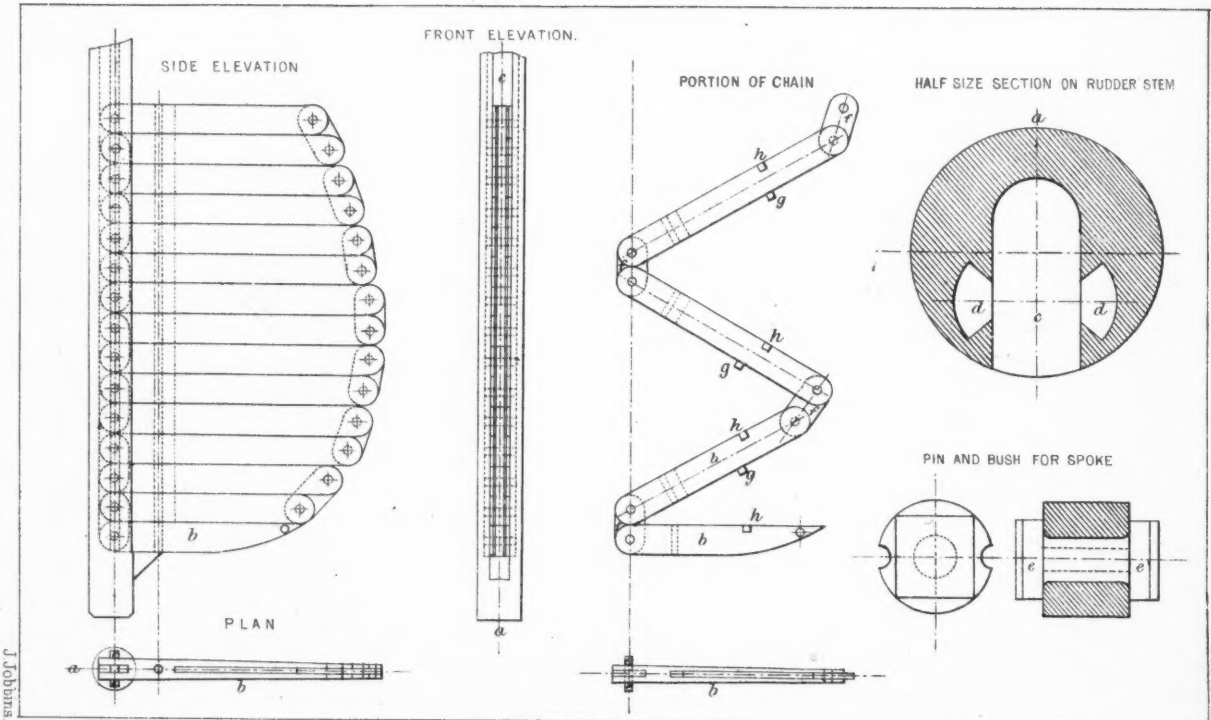
I NEED not, I am sure, suggest to you how necessary it must be, not only in the Navy, but also in the Packet and Merchant Service, to be prepared in case of accident to supplement that governing power, without which, however well a ship may be commanded, manned, and steam-powered, she must be comparatively helpless. In the days when our Navy was composed of wooden ships, it was considered a great feat of seamanship to rig a jury-rudder, and with it take the ship safe into port.

Take the memorable case of the "Pique," commanded by Captain Rous, when the ship, by means of a Pakenham rudder, was navigated across the Atlantic, and gained for that gallant officer a name, which will live in the traditions of the Navy.

In the present day, when our Navy is mostly composed of iron-clads with steam-power, it is far more difficult than formerly to extemporise a rudder, not only that ships when rudderless are more difficult to steer under steam than under sail, except in cases of twin-screws, but also from the guys fouling the screw, and further, from the rudder-trunk being too small to take a topmast. When we look at the various models of jury-rudders on the table before us, I think that you will agree with me that it would be impossible to apply any one of them to an iron ship within reasonable time.

It has been said, that the loss of rudder is of such rare occurrence, that it is hardly necessary to be prepared with an expensive fitting to meet such an uncommon contingency. In the Navy, no doubt the loss of a rudder is almost unknown, but still cases have occurred. The "Inconstant" lost her rudder shortly after leaving Pembroke. The "Lord Clyde," when on shore off Pantallaria, had her rudder so damaged as to be almost useless. In 1866 a splendid frigate lost her rudder off Cape Horn, and was nearly wrecked in consequence. The Constructors' Department of the Navy, fully alive to the necessity of being prepared to meet every contingency, have always endeavoured to supply the want.

In the Packet and Merchant Service generally, the loss of rudder is


SIDE ELEVATION
FRONT ELEVATION.
PORTION OF CHAIN
HALF SIZE SECTION ON RUDDER STEM
PIN AND BUSH FOR SPOKE
PLAN
a
b
c
d
e
g
h

J. Jobbins

of far more frequent occurrence; and the first inducement I had to consider the subject was a paragraph in the *Times*, which told of seven steam-ships being adrift in the Atlantic, with lost and damaged rudders. How many of that sad list of "missing vessels" may be attributable to similar accidents we shall never know.

The plan which I now lay before you, Gentlemen, is still in its infancy. I am by no means wedded to its details. I dare say, in practice, some may be found defective, others may be greatly improved upon, and it is almost impossible, in models, to work out minute details in a satisfactory manner. You may, however, be glad to know that I have already tried a rudder which, in a sea-way, was shipped in five minutes, and steered a vessel of 35 tons. I am happy to say that the Lords of the Admiralty have permitted me to forward plans, with a view to its being tried on a larger scale; and though I have doubt that, with heavier weights, obstacles will have to be overcome, yet in this world nothing can be done without patience and perseverance, and if I can only succeed in helping my brother sailors from a lee-shore when rudderless, I shall feel myself amply repaid.

Explanation of Plan.

(*a*) is a trunk or cylinder, composed of wrought iron, with a large groove (*c*) cut out of it; dovetail grooves (*d*) are again cut in groove (*c*).

(*bbb*) are pieces composed of wood, plated with iron, and fitted at one end with movable pins (*e*) with dovetail heads. When the old rudder is lost or removed, trunk (*a*) is lowered down the rudder-hole, which it is made to fit, until it rests on the sole-plate. If this should be carried away, or there should be none, (*a*) is supported in its place by a movable collar, on rollers, and the rudder-chains are secured to the lower end and set taut to each quarter. The pieces are then lowered, end-on, down the trunk-pin end *first*. If the pieces (*bbb*) are used separately, a tripping-line from the lower end cants each piece out at right angles to (*a*). As soon as it touches the piece below it, and it is prevented falling out of the trunk altogether by the pins (*e*), which run in grooves (*d*), the form of the pins and grooves preventing the tube from opening when lateral strain is brought on it. If (*bbb*) are fastened together by the links (*ff*) as in an endless chain, each piece on reaching the bottom forces out the piece above it, and as each piece falls on the top of the piece below it, the studs (*gg*) fall into the slots (*HH*). When the rudder is made up, the whole is tautened up by a screw down the trunk.

Friday, April 23rd, 1875.

MILITARY MODEL APPARATUS,

Invented and Patented by Captain E. Podmore Clark.

General Sir William Codrington, and numerous other Officers being present, Captain E. Podmore Clark, Instructor of Musketry to the Herefordshire Militia, and late Lieutenant 62nd regiment, exhibited and explained his improved Military Model Apparatus for illustrating military drill. Captain Clark briefly explained that his object had been to introduce an apparatus by means of which simultaneous turning of ranks (front and rear rank), in any direction required, might be achieved so as accurately to illustrate all retiring movements and deployments, &c., which had never yet been invented. In this he has been successful, after much study, and the apparatus, as now complete, was composed of six companies, with Officers, guides, and markers complete; band, pioneers, colours, mounted Officers—a complete regiment.[1] The figures representing the men are mounted on brass cog-wheels interlocking, and, by moving one wheel, all ranks can be turned simultaneously in any direction required, as on parade. By placing two companies to represent a regiment, brigade drill can be exemplified, while it also teaches squad, company, and battalion drill.

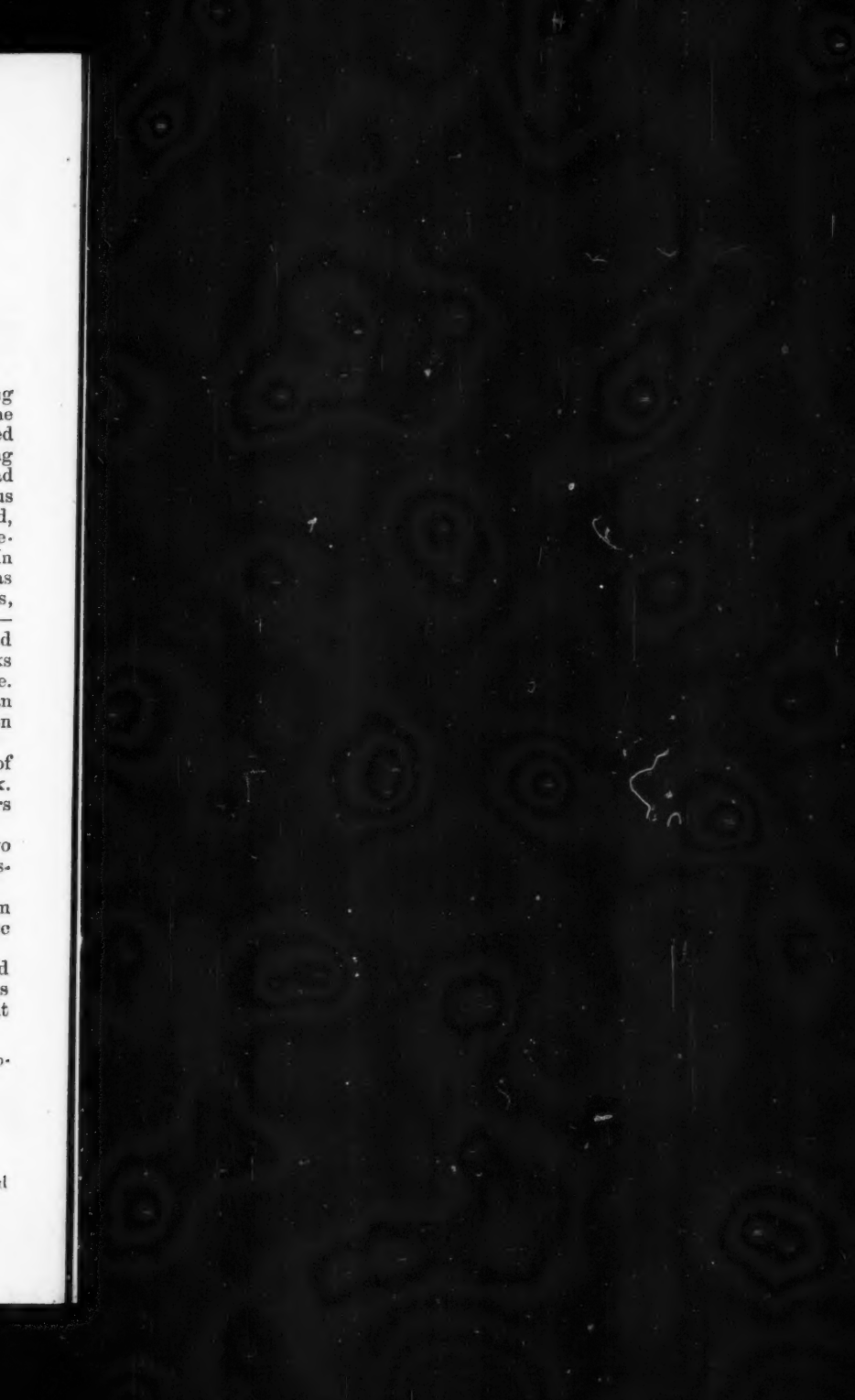
The positions of guides and markers are also shown by means of coloured stars for the various movements in the supernumerary rank. There is also a separate model, which shows the formation of fours (right, left, deep, about, &c.).

Several military evolutions, including squares, four deep, and two deep, change of front when in line, deployments, &c., were then satisfactorily illustrated.

The inventor stated that he had received high commendation from His Royal Highness the Duke of Cambridge and from the War Office Authorities.

Sir William Codrington, at the conclusion, said that the Council had been glad to afford Captain Clark an opportunity of exhibiting his ingenious invention, and expressed to him the thanks of those present for so doing.

[1] A complete model may be seen at Messrs. Clowes and Sons, Military Publishers, Charing Cross.

ERRATUM.

In Major-General Sir F. Goldsmid's Article, on "Journeys between Herat and Khiva," page 5, last line. For "Russian Khurasan," read *Persian* Khurasan.